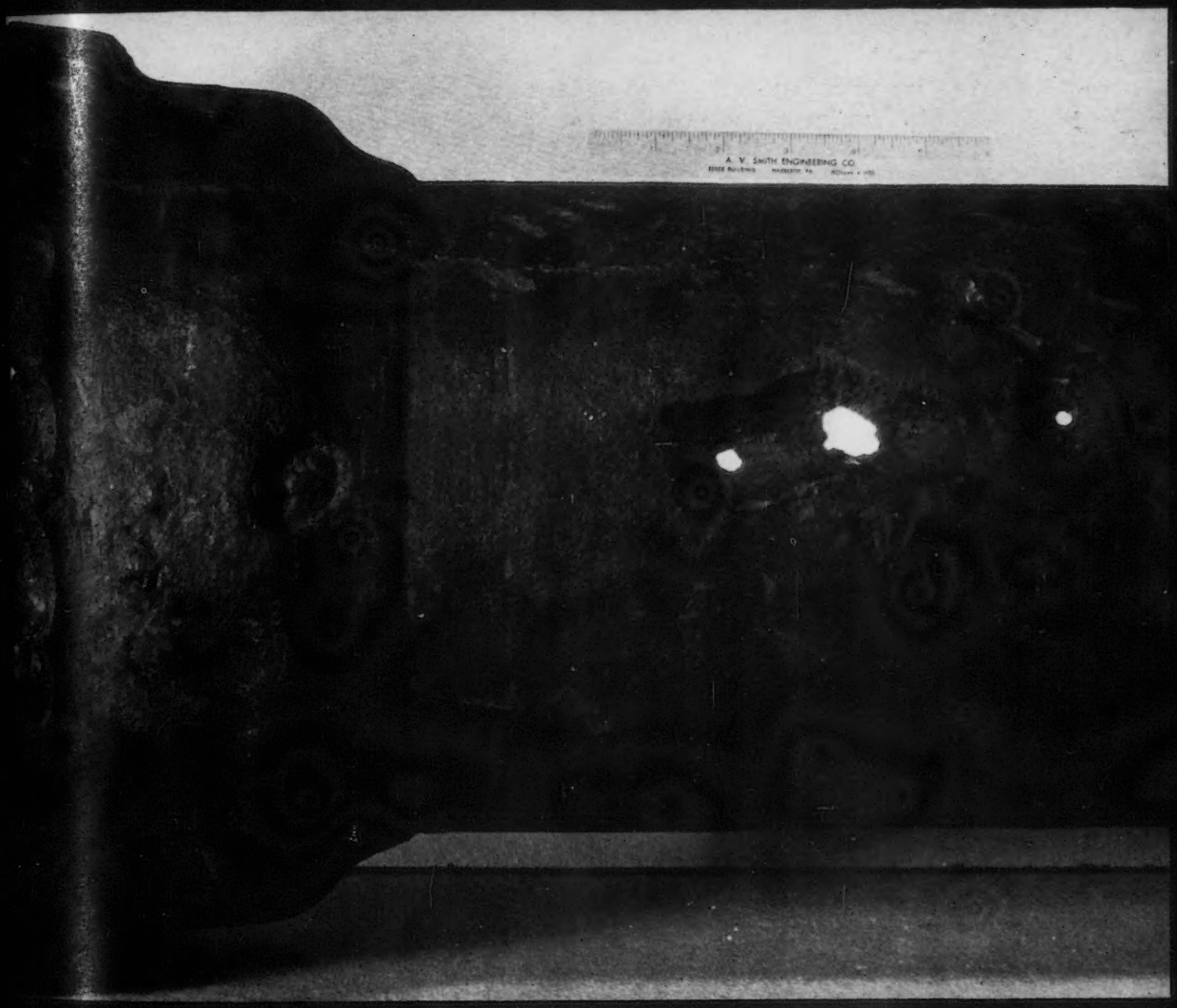
Corrosion

Official Publication
NATIONAL ASSOCIATION OF CORROSION ENGINEERS



APRIL 1952 VOL. 8

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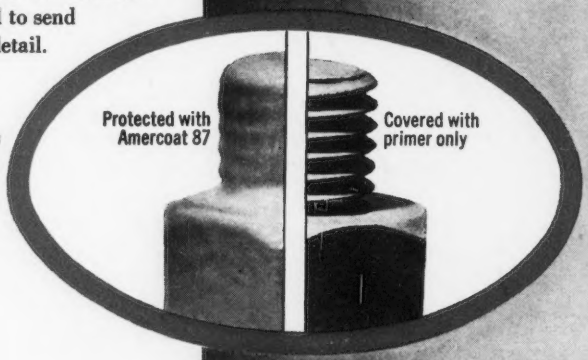

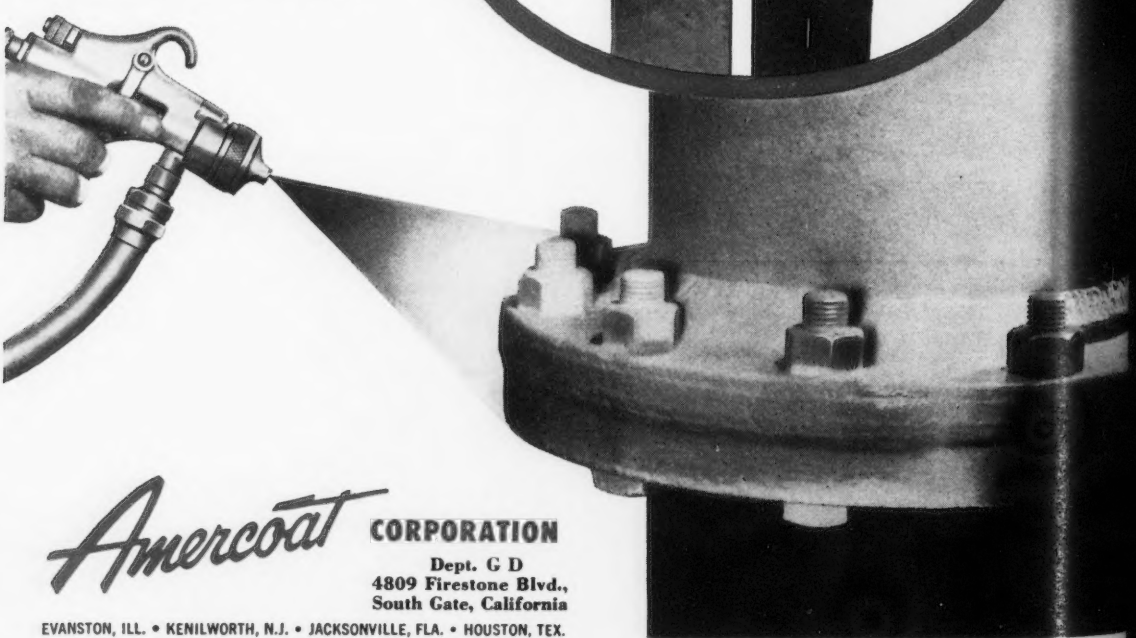

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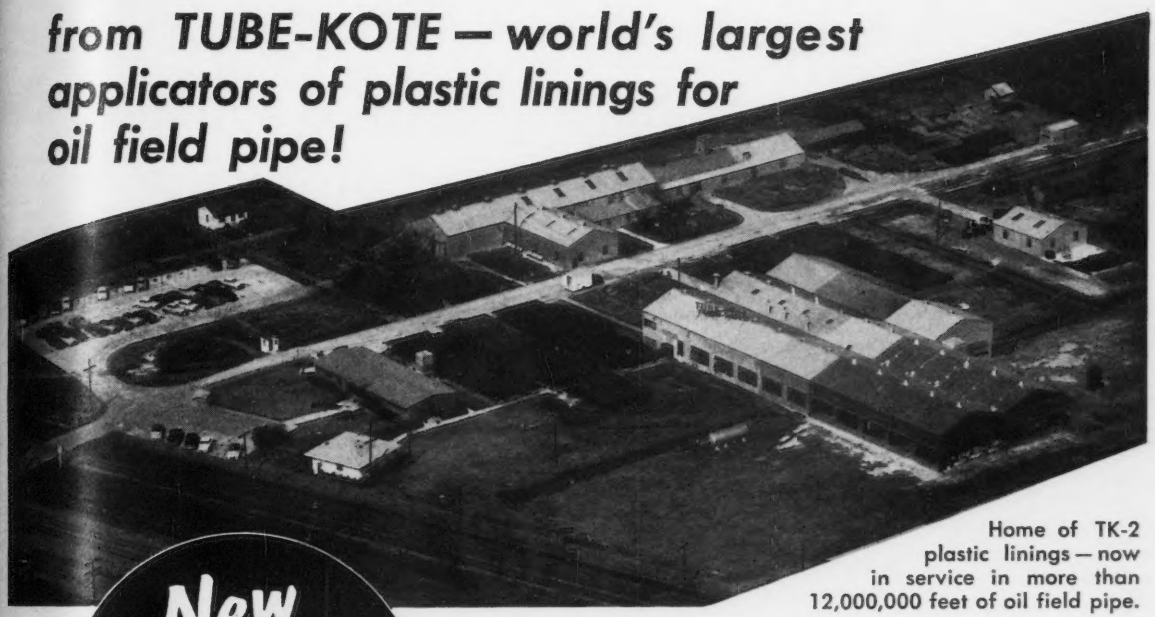

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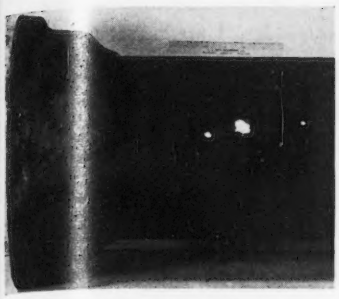

THIS MONTH'S COVER—When a storm caused a short circuit, a substation outage caused currents estimated at 2000 amperes to flow from this 8-inch cast iron water main to a culvert crossing it at right angles one inch away. The resulting arc penetrated the main and culvert. Note splatter and remains of puddled metal.

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(Continued on Page 6)

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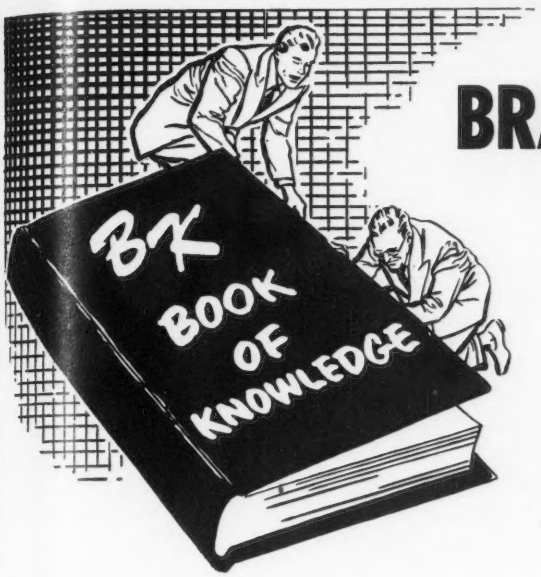

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Harco's job is protecting you . . . protecting your investments . . . protecting your profits. Harco job-engineered systems provide the necessary testing, drawings, materials and installation techniques. Harco installation and contracting service is completed to customers specifications, and it covers as much or as little of the total job as is required. Materials and supplies available from Harco are complete from anodes to rectifiers.

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PROTECT TANK and PIPE INTERIORS

Use *Copon* . . . the revolutionary EPOXY RESIN COATING

Here are the reasons why "Copon" is attracting the attention of leading corrosion and petroleum engineers:

- **It has exceptional tenacity, will adhere to metal surfaces longer and under more difficult conditions than any other coating yet tested.**
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WmSON
STYLE 4 THINSULATOR
The "THIN" insulator for pipe in casing

Clearance insures free movement into casing
THINSULATOR band, flexible steel lined with synthetic rubber. Band clamped with steel stud bolts.
steel runners
pipe line
casing

SIZES 6 x 10 to 36 x 40

THINSULATORS EQUALLY SPACED THRU CASING

A SNAP TO INSTALL just snap on pipe tighten studs . . .

WmSON CENTERING CRADLE
short massive INSULATOR centers pipe at casing end permitting easy installation of "Z" BUSHING

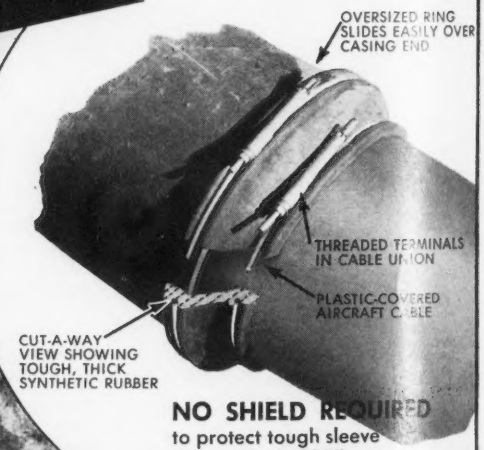
- carries weight of backfill dirt and insulates pipe from casing
- EASY TO INSTALL: Simply lift pipe and slip into place

SIZES: *any combination of pipe and casing sizes.*

PIPE LINE CASING PIPE LINE

Here's why . . .
Pipe line construction specs. include WmSON BUSHINGS, INSULATORS & CRADLES for cased crossings . . .

WmSON
"Z" BUSHING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FOR PIPE 6" AND UP IN CASING 4" OR 6" LARGER

They are "ENGINEERED" for LASTING ECONOMY . . .

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Autoclave of Annealed Ductile Cast Iron... the first pressure vessel made by the Cooper-Bessemer Corp., Mt. Vernon, Ohio. Designed and approved for internal pressure of 350 p.s.i. at 300°F. with jacket pressure of 125 p.s.i. at 350°F. Oval manhole cover, blind flange, two agitators and thermometer well are also of annealed ductile cast iron to ASTM Spec. A-339-51-T. Body weight: 18,485 lb. Cover: 5,000 lb.

Ductile Cast Iron

Specified for Pressure Vessel

This 600 gallon autoclave of ductile cast iron is for use in a methylation process.

Unlike conventional flake graphite cast irons, ductile iron has a spheroidal graphic microstructure. That's why its mechanical properties are closer to those of steel than to those of gray iron.

Take a look at these test figures from heats used for the autoclave:

Ultimate tensile strength, p.s.i.	64,500/69,700
Yield strength, p.s.i.	49,000/54,700
Elongation in 2" %	19.5/23.5

Combining the process advantages of cast iron and the product advantages of steel, ductile cast iron is a logical material for process equipment.

See for yourself how this economical iron . . . several times stronger than gray cast iron, and up to twelve times tougher . . . can help you. Send for a copy of "DUCTILE IRON, The Cast Iron THAT CAN BE BENT!" This booklet is yours for the asking. Write for it now.

ductile iron . . . the cast iron that can be twisted and bent

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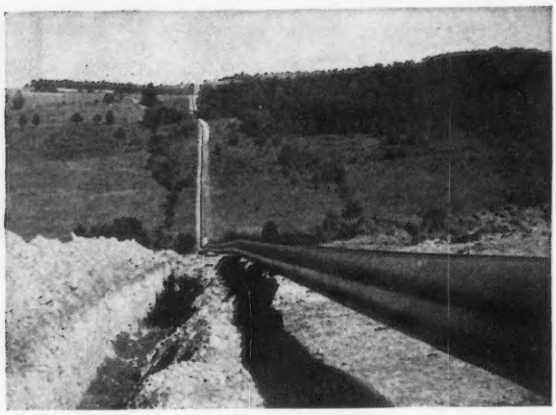
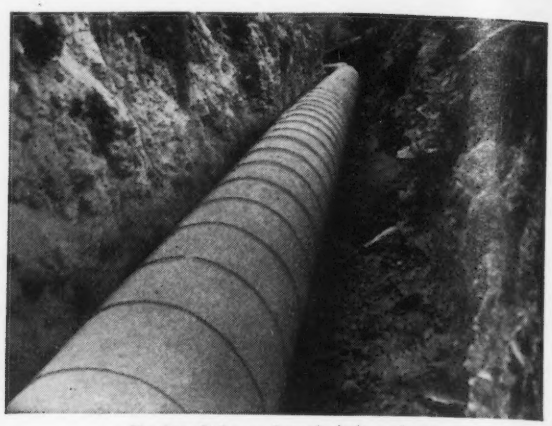
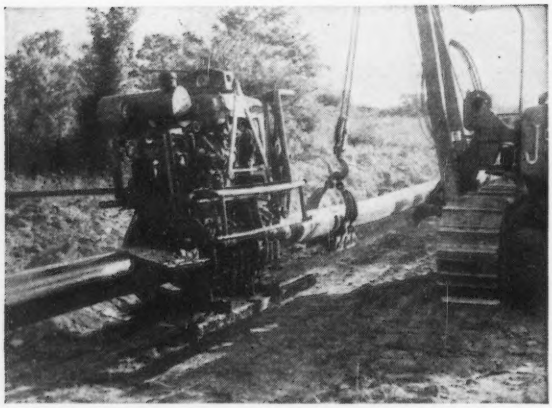
THE INTERNATIONAL NICKEL COMPANY, INC. 67 Wall Street New York 5, N.Y.



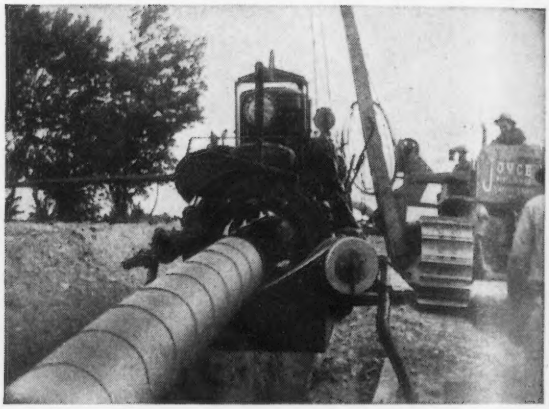
Pipeline laid over rugged terrain.



Pipeline ditch cuts through shale and rock.



Cleaning Machine and primer application.



NO-OX-ID and wrapper applied by Traveliner.

Why Corning Natural Gas relies on NO-OX-ID for pipeline protection

In 1954 Corning Natural Gas Company, Corning, N. Y., began expansion of their transmission system with 16 miles of 12-inch and 7 miles of 10-inch pipe. Dearborn NO-OX-ID Coating Combinations were specified. Over-the-ditch pipe protection was hot applied by a traveling, coating and wrapping machine using NO-OX-ID 2-C Primer, NO-OX-ID 6-X Coating and NO-OX-ID Reinforced Asbestos Wrapper.

WHY NO-OX-ID IS PREFERRED:

When asked how his crew liked working with NO-OX-IDs, the contractor, Mr. Joyce, stated: "They had never previously applied hot NO-OX-ID. The ease and convenience of application, plus freedom from personal hazards, caused complete satisfaction all around." As a result, Corning Gas plans to specify NO-OX-ID protection on additional pipeline reconditioning during 1955.

Before you specify on your next job, check with Dearborn...a Pipeline Engineer is available for consultation.

it pays to specify

Dearborn NO-OX-ID®

DEARBORN CHEMICAL COMPANY • Merchandise Mart Plaza • Chicago 54, Ill.

ADVANTAGES OF NO-OX-ID PROTECTIVE COATING

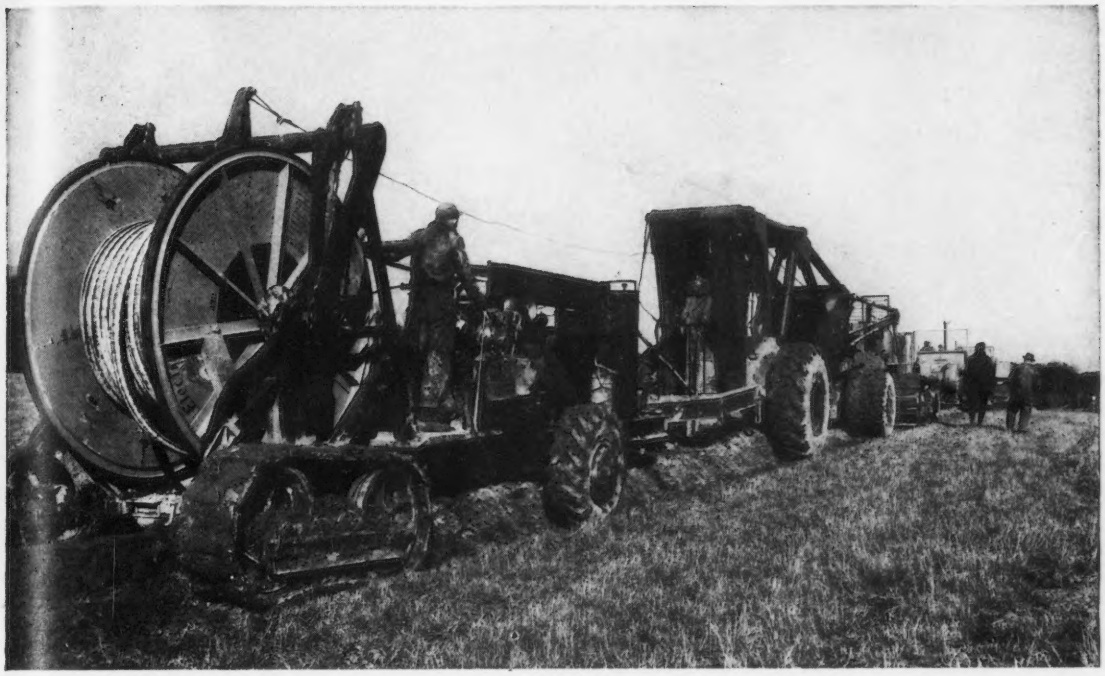
- ★ Applied hot or cold
- ★ By hand, by Traveliner or at the mill
- ★ No noxious fumes
- ★ Requires less equipment
- ★ Lasts longer

WRITE FOR BULLETIN

"Protecting Underground Pipe from Corrosion with NO-OX-ID and NO-OX-IDized Wrappers" tells the story. Your copy is ready upon request.

LEAD

The Standard Protective Sheathing for Cable



Twenty-seven ton cable-laying plow; it digs a trench in the ground—5 ft. deep, if necessary—feeds the cable into it, covers the cable and moves on, all in one continuous operation.

EXTRUDED lead tubing has been used as protective sheathing on overhead and underground electric cable for either voice or power transmission, since the late 1800's. The choice of lead for this purpose was dictated chiefly by a number of highly desirable characteristics inherent in the metal. The metal's pliability facilitates the reeling and unreeling of the cable; its low melting point permits the sheathing to be extruded over the core without damage to the insulation, and it is the only common metal which successfully withstands all of the corrosive influences encountered in the service-life of cable.

Lead alloyed with small amounts of other metallic elements is characterized by its relatively high tensile strength and resistance to fatigue — thus minimizing mechanical failure resulting from normal fatigue and tensile stresses. This is of especial importance since the stresses which are most likely to cause fatigue failure in aerial and duct cables are either oscillatory in nature or are the result of dimensional changes from alternate heating and cooling.

Of particular importance is the fact that lead is impervious to moisture and is highly resistant to atmospheric and soil corrosion or — in the case of oil-filled submarine power cable—to salt water corrosion. For lead exposed to the air develops its own protective film, usually an oxide, while the film that forms on lead buried in the ground may be silicate. Once these protective films have formed on lead the metal may be preserved indefinitely. Ample evidence to this effect is the lead pipe which, laid by the Romans nearly two thousand years ago, is still in use today.

Other factors in favor of lead sheathing is that it is malleable, and that convenient lengths of the cable are easily joined with the help of two other lead products, lead sleeves and solder. Finally, when the life of the cable is spent, the lead is easily reclaimed and can be returned to the market for another cycle of service.

ST. JOSEPH LEAD CO.

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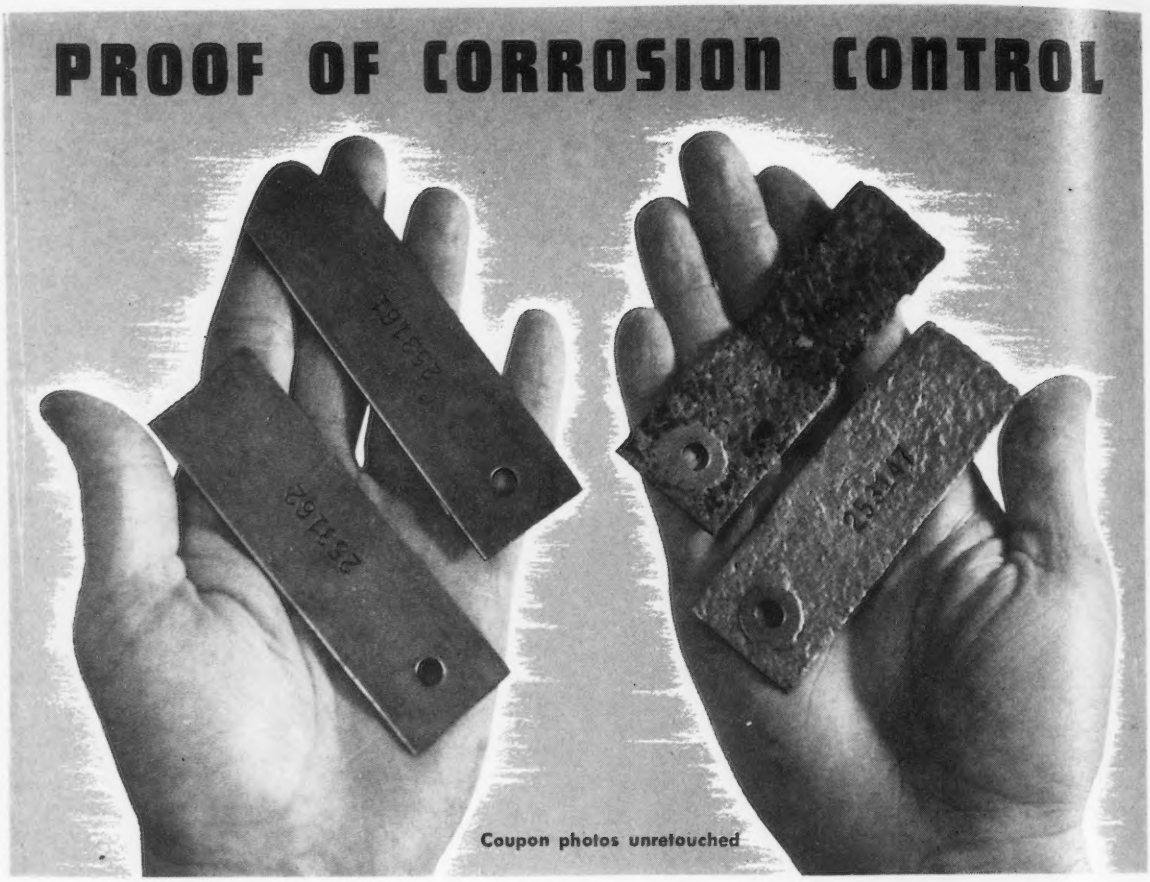
THE LARGEST PRODUCER OF LEAD IN THE UNITED STATES

PROOF OF CORROSION CONTROL



Coupon photos unretouched

with Visco® ANTI-CORROSION TREATMENT

IT took only 30 days for the two steel coupons shown at right above to corrode almost away in the stream of a secondary-recovery well in Kansas. Both coupons, where not corroded through, are wafer thin. An anti-corrosion chemical was being fed at the rate of one pint per day, yet the average corrosion rate on the coupons was 216 mils* per year.

In the same well, Visco-treated with the same amount of chemical per day, the coupons at left above showed a corrosion rate of only 8.1 mils per year after 29 days' exposure.

Visco Chemicals cut the corrosion rate over 96%!

For corrosion control *results* and treating *economy,* call your Visco Representative, *now.*

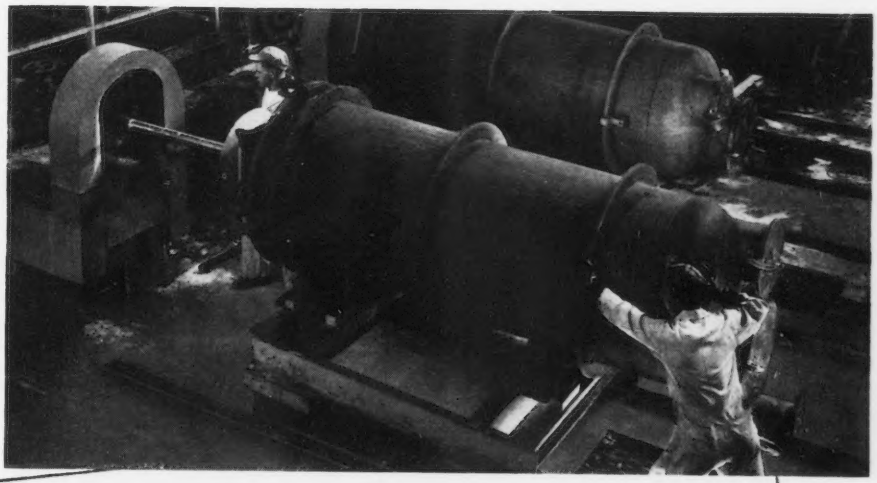
*1 mil=.001 inch. A corrosion rate of 216 mils per year means that the corrosive attack, if uniform, would have corroded away the entire surface of the metal to a depth of .216 inches in a year. However, the real danger of high corrosion rates, as the coupon shows, is the much deeper and faster penetration occurring at localized areas.

VISCO PRODUCTS COMPANY
INCORPORATED
2600 Nottingham at Kirby, Houston 5, Texas
Telephone: MAdison 0433

Visco . . . CONSISTENTLY EFFICIENT OIL INDUSTRY CHEMICALS

ALCOPLATE*

Chemically Coats any Metal Surface with Protective Nickel



A pressure vessel is positioned for internal coat of ALCOPLATE. In addition to operating one of the largest plants for chemical nickel-plating, ALCO has complete facilities and extensive experience in the design and fabrication of heat exchangers, pressure vessels, etc.

Solves Corrosion Problems in the Chemical, Petrochemical and Related Industries At Low Cost

No matter how intricate the geometries involved—on surfaces impossible to plate electrolytically or to clad—ALCOPLATE provides a uniform coating of protective nickel. Applied to inexpensive base metals, its corrosion resistance *is as good as or better than* pure or wrought nickel or other costly alloys. It will pay for itself many times over through prolonged life of process equipment.

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1. Maximum protection at minimum plating coat—Zero porosity is obtained in plating coats of less than a half mil (.0005).

2. Plate adhesion is excellent—Steel specimens pulled to the yield point show no flaking or spalling.

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5. Appearance of plate—A polished appearance can be obtained by polishing the base metal prior to plating. ALCOPLATE can be buffed to a high luster.

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*ALCOPLATE—Trade-mark registration applied for. Application of the Kanigen® process. "Kanigen" is a mark identifying chemical deposition of high nickel, low phosphorus alloy by General American Transportation Corporation and its licensees, and the coating resulting therefrom.

THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS

is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

(f) To contribute to industrial and public safety by promoting the prevention of corrosion as a cause of accidents.

(g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.

(h) To invite a wide diversity of membership, thereby insuring reciprocal benefits between industries and governmental groups as well as between individuals and corporations.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers and elected directors are nominated by a nominating committee in accordance with the articles of organization. Election is by the membership.

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 1061 M & M Building, No. 1 Main Street, Houston 2, Texas.

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Topic of the Month

Solution of Aircraft Wing Exhaust Gas Corrosion Problem Is Nearer

By S. K. COBURN*

AMONG its many corrosion problems, the aircraft industry is concerned particularly with the behavior of impinging exhaust gases upon the wings and fuselage of the plane. These gases, somewhat similar in composition to automobile exhaust gases, carry with them a volatile lead compound originating in the anti-knock ingredient, lead tetraethyl. Normally, to each gallon of aviation gasoline there is added from 3 to 45 milliliters of a liquid whose composition approximates 1.7 parts of lead tetraethyl to one part of ethylene dibromide. The latter material behaves as a scavenger compound preventing internal lead deposition by forming the relatively low melting (370 C) and volatile compound—lead bromide (bp 916 C). It is this compound that has been identified as comprising as high as 90 percent of the deposit found on the plane's wing. This substance, along with moisture, initiates a series of reactions believed responsible for a very serious corrosion problem.

When it is realized that it costs some $20,000 to replace a section of tank skin, during which time the plane is kept out of revenue producing service from two to three weeks, it becomes clearly evident that this form of corrosion merits consideration. It has been found that airlines operating in areas of high relative humidity suffer more from this phenomenon than those operating in areas of low relative humidity. Also, where a strict schedule of cleaning and protective maintenance is not carried out, this type of corrosion exacts a much higher toll.

Considerable chemical investigation has been carried out by the aircraft manufacturers and producers of anti-knock compounds leading into the complex and little understood field of solid state reactions. In addition to the carbonaceous products of combustion a fairly large number of inorganic compounds of simple and complex composition have been identified through X-ray diffraction analyses. However, since the major exhaust gas deposit on the plane's exterior has been shown to be lead bromide, applied research laboratory investigations have commenced with this material.

It has been learned that the dry components of the various synthetic salt mixtures made up in accordance with the analysis of deposits removed from exhaust assemblies do not corrode aluminum. However, when anhydrous lead bromide is placed on aluminum sheet and exposed to atmospheres of various relative humidities ranging from 100 to 20 percent, an almost instantaneous reaction starts in which gaseous emission is observed and a blackening of the aluminum sheet becomes apparent. This fact points rather conclusively to the important role played by water in an understanding of the mechanism of the corrosion reaction. It has been postulated that relatively insoluble lead bromide undergoes reaction with water leading to the formation of hydrobromic acid and lead oxide. The hydrobromic acid reacts with the electrolytically active metal aluminum to form the water-soluble compound aluminum bromide. This highly active deliquescent substance reacts with any available moisture to form a gray-white precipitate of aluminum hydroxide while regenerating an equivalent quantity of hydrobromic acid. It is believed this simple cycle of acid generation might be self-propagating. The precipitate develops a blister-like mound, seemingly snuffing out further corrosion activity. However, due to its fragile nature, the blister fractures and bare metal soon is exposed to the action of the newly formed acid. As a by-product of the acid reaction with aluminum, hydrogen is made available and proceeds to reduce the complex oxides and hydroxides of lead to the metallic form which shows up as a gray-black smear.

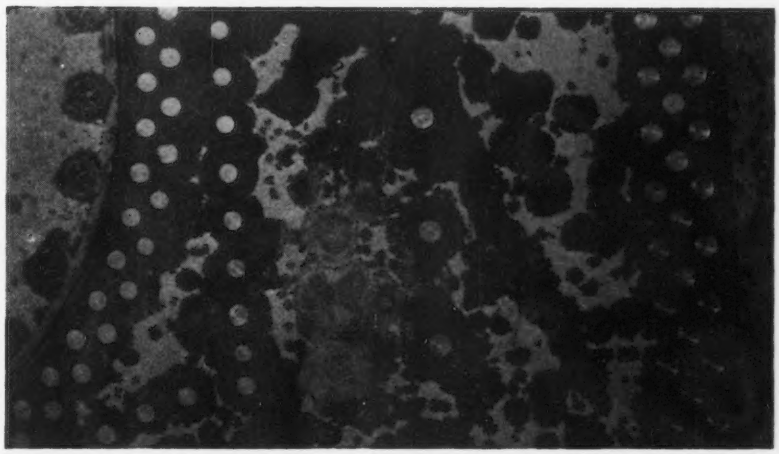

Figure 1—An example of the effect of corrosion on wing surface area. Note orientation of major corrosion in vicinity of rivets.

An obvious procedure for overcoming this type of corrosion is the use of a barrier film. An aircraft manufacturer's chemical laboratory staff has examined numerous coatings and chemical systems consistent with necessary weight restrictions. In nearly every case failure was encountered because of poor adhesion, inadequate physical properties, vulnerability to cleaning solutions and solvents, poor abrasion resistance to foot traffic on wings and an inability to resist the solvent action of synthetic hydraulic fluids.

Recently a new polyester resin-type tape with good detergent and solvent resistance, high tensile strength and complete inertness to hydraulic fluids has appeared on the market. This material is being tested and preliminary results appear promising. At present the use of one of the epoxy resins has had a service experience with encouraging results. Additional planes are being treated for service tests and it is not inconceivable that a long awaited ideal remedy for the exhaust gas corrosion problem soon may be available.

Acknowledgment

The author is grateful to D. P. Jensen, Chemist, Douglas Aircraft Company, Inc., Santa Monica, California, for helpful discussion in the preparation of this article.

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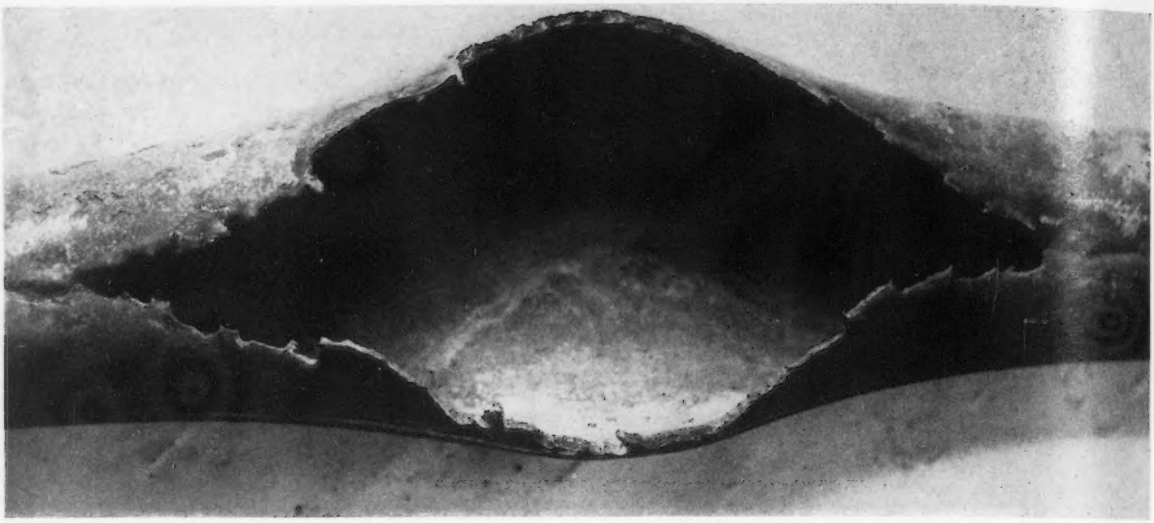

Figure 1—The burst tube, A-25.

Case History of Failure of Marine Boiler Tubes By Stress Corrosion Cracking*

By R. D. BARER

Introduction

FOR A RATHER ENTERTAINING historical review of boiler failures, particularly those in the latter part of the 19th Century, Zapffe's paper "Boiler Embrittlement"[1] is worth reading. His scholarly effort, based on 427 references, stimulated discussion and disclosed pertinent aspects of research into the mechanism of boiler cracking.

More recently, in their excellent paper "Marine Boiler Deterioration," Slater and Parr[2] summarized the experience of the British Admiralty during the 2nd World War. Among the examples of other forms of boiler deterioration, only one example of stress-corrosion cracking (caustic cracking) is presented: a typical crack between rivet holes. Further, they indicate that this cracking is extremely rare in boilers using distillate feed. This general experience that stress-corrosion cracking is extremely rare, particularly in boiler tubes, is repeated throughout the literature.[3,4,5,6] In fact, as recently as November, 1952, the British Engine Technical Report[4] on "Caustic Cracking in Steam Boilers" states: "...it is not encountered where the construction is seamless or welded, except occasionally at attachments for fittings."

Accordingly, it is believed that the details of one such "rare example" will be of wide interest.

Investigation of Marine Failure

Recently, a main boiler on one of Her Majesty's Canadian ships was damaged by a burst tube. Records

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Abstract

Failures by stress-corrosion cracking of marine boiler tubes are commonly the result of a concentrated caustic solution in contact with stressed boiler metal. Usually the concentration of the caustic results from leakage between seams and around rivets, or capillary action and subsequent evaporation.

A rare example of the same type of failure is one where no seams or crevices exist for concentrating the boiler solution by leakage; this is failure resulting from concentration of the boiler solution right on the steam generating surface of the boiler tube. Details of such a failure are discussed. In particular, it is shown that the attainment of the necessary caustic concentration and stress levels is feasible. It is pointed out that stress need not be as high as is commonly believed.

The mechanism of caustic cracking as understood today is reviewed; that is, electrochemical action aided by stress. In effect, this serves to include caustic cracking among such phenomena as the season-cracking of brass and the stress-corrosion cracking of stainless steel. It is commonly accepted that this type of failure is rare. That it does occurr suggests that some thought might be directed to preventing channelling by hot gases and to alternative chemical treatments which do not rely on caustic.

at the time of the failure, during which the ship was steaming steadily at half load, do not indicate anything unusual in operating conditions.

The boilers on this ship are water-tube Admiralty 3-drum type. In this type of boiler there are 50 tubes in each row and they are numbered from the burner end. The rows are also labelled right and left as viewed from the burners. The rows are lettered alphabetically from the flame outward. Damaged tubes were found only in A row, which is adjacent to the flames and in B row, which is one row removed from the flames.

The investigation was initiated when tube A-25 from the righthand side of the boiler was submitted. The burst portion of this tube is shown in Figure 1. Subsequently, other tubes were made available, including several which leaked when a hydrostatic test was applied following the shutdown of the boiler.

a. Visual Examination

No apparent metal wastage occurred in the burst tube A-25. This was confirmed by measurement and can be noted in Figure 1. A minor amount of stretching did take place at the time of the burst. This stretching could have taken place over a period of time except that had it done so, it is likely that a small leak, rather than the burst would have relieved the pressure.

Closer examination of the metal at the edge of the burst showed that the metal had parted along apparent "plates," except for the small percentage of the metal which stretched. Cracked metal would give a plate-like appearance on fracture. In fact, near the edge of the burst, many fine cracks, ⅛ to ¼ inch long, were to be seen. Subsequently when the tube was cut into lengths to facilitate micro-examination, it was noted that a zone of cracks extended longitudinally for approximately four inches from the burst along the inner surface of the tube.

A thin film of copper was noted on the inner surface of this and other tubes.

Leaky tubes from B row (also right-hand side) namely, 38, 39, 40 and 41, were examined. The ruptures and stretching of metal in between as shown on tubes B-39 to B-41 inclusive, (Figure 2) indicates failure by the same mechanism. Although these tubes had opened slightly, rather than having burst open, they had apparently been subjected to the same mechanism which caused tube A-25 to burst.

To show in some detail the cracking which was readily visible to the naked eye, tube B-40 was split in two and is reproduced as Figure 3.

The absence of fully ductile breaks strongly suggested some type of embrittlement had allowed the metal to part with apparent ease and the full and partial rupturing of tubes indicated that a change in operating conditions, presumably overheating had occurred at a particular instant.

b. Micro-Examination

Tube A-25, whose bursting initiated the investigation, was given a thorough and detailed micro-examination.

Small samples were cut from the tube at approximately four inches from one end of the burst, (Sam-

Figure 2—Showing the ruptures on Tubes B-39, B-40 and B-41 which are also from the right-hand side of the boiler.

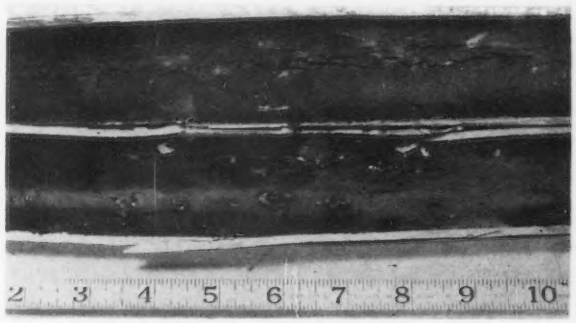

Figure 3—Tube B-40 split open in the ruptured region to show the extent of the cracking.

Figure 4—Inner surface of tube A-25 at four inches from the burst. Many fine cracks may be noted. Approx. 11x.

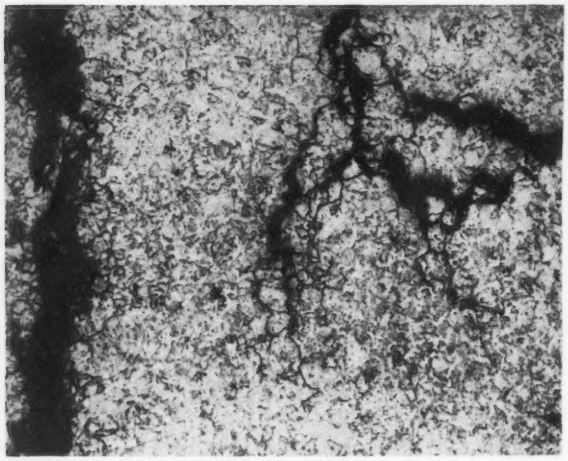

Figure 5—Photomicrograph of an area from Figure 4 which was enlarged to bring out the detail of the intergranular cracking. Approx. 105x.

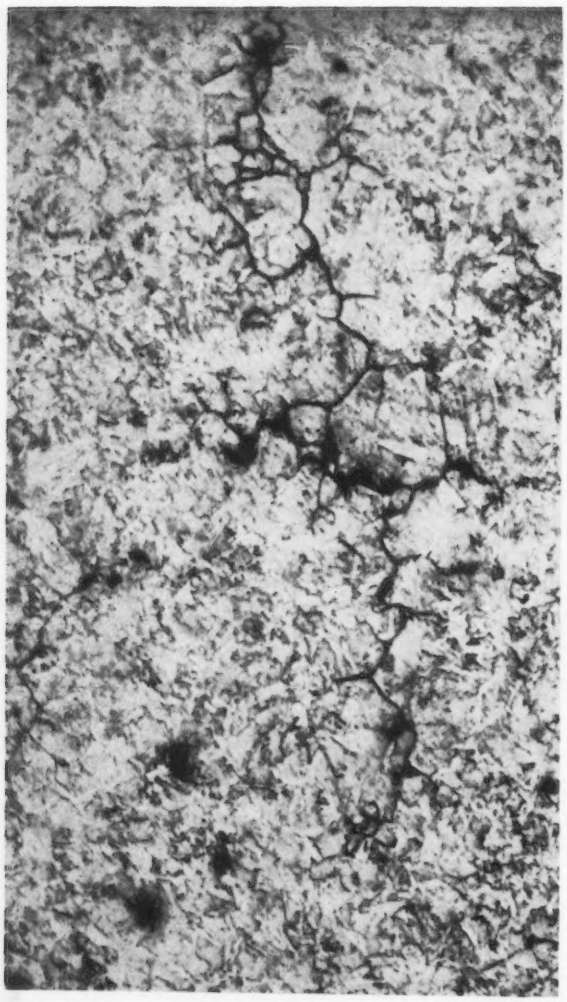

Figure 6—Photomicrograph of another area from Figure 4 which was enlarged to show more of the definitely intergranular nature of the cracking. 240x.

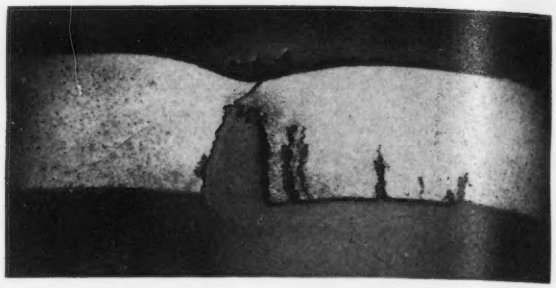

Figure 7—A section through the tube wall near the end of the burst (A-25) showing the ductile necking-down of the outer metal and final rupture on a 45 degree plane. Also shown are five additional cracks which progressed in an intergranular manner. Approx. 7x.

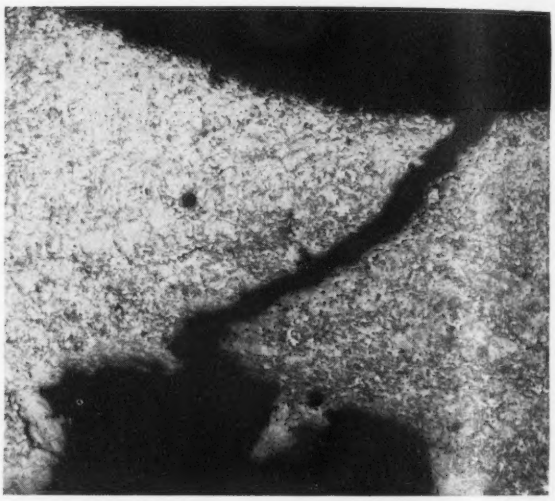

Figure 8—Photomicrograph of the ductile portion of the break in Figure 7 showing complete absence of intergranular cracking in outer skin. Approx. 106x.

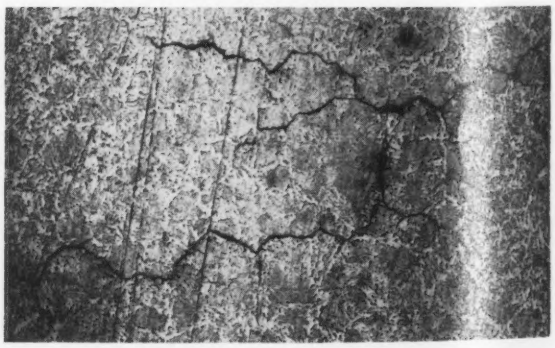

Figure 9—Photomicrograph showing fine intergranular cracking on the non-fire, inside surface, of tube A-25 near the burst. Approx. 210x.

ple A) and just beyond the same end of the burst, (Sample B).

The face of Sample A, which is the inner surface of the burst tube is shown at eleven magnifications in Figure 4, after polishing and etching. In addition to the major cracks, several fine cracks are present.

Figure 5 shows a small portion of Figure 4 enlarged to 105 magnifications. It may be seen that the fine cracks follow grain boundaries and are, therefore, an indication of intergranular corrosion.

Figure 6 is another small area of Figure 4 enlarged to 240 magnifications. Here also the fine cracking around grains may be noted. This area is typical of many others on Figure 4 when viewed at higher magnification. Examination of the microstructure showed that the metal had been above 1500 F and had been rapidly cooled from this temperature. It is believed this heating occurred just prior to final failure.

A cut through the tube wall, (Sample B), is shown in Figure 7 at seven magnifications. Intergranular cracking was prevalent and was readily seen at higher magnifications. No intergranular cracking was found in the necked-down portion of what corresponds to the outside 25 percent of the tube wall which had retained its normal ductility. This area is shown in Figure 8 at 106 magnifications. (There is a short length of intergranular cracking in the lower left part of the major crack).

The fine ends of all cracks noted were intergranular. This means that the cracks were initiated and also progressed by the same mechanism or cause. If a crack is propagated by fatigue or by corrosion fatigue, the fine ends rupture the grains of metal rather than going around them.

Many other samples were cut from different areas of the burst tube (A-25) to determine the extent of the intergranular cracking. These samples showed that the metal had been weakened intergranularly for approximately 21 inches on each side of the burst on the fire side, (in the sense of being closer to the flames) and somewhat less on the opposite side of the tube, in both cases, internal. Cracking, typical of that found on the non-fire side is shown in Figure 9 at 210 magnifications. Incidentally, the fact that the mild steel had been overheated and then rapidly cooled is readily noted in the microstructure of Figure 9.

Tubes B-38 to B-41 inclusive were also given a detailed micro-examination over a number of samples taken at intervals along the tubes. A micro-section through the wall of tube B-39 is here included as Figure 10. This is an excellent example of the typically intergranular cracking found in practically all the sections examined. It is also indistinguishable from cracking exhibited by the steel of an autoclave exposed to 50 percent caustic soda at 250 F and 400 psi as reported by Copson.[7]

In the course of checking for the extent of embrittlement, it was decided to try examination under a binocular microscope rather than the more tedious method of micro-examination. This is described below.

c. Macro-Examination

By trial, it was established that examination under a binocular microscope at 20 or 30 magnifications would readily differentiate between embrittled and non-embrittled tube. Accordingly, half-inch slices were cut across a tube at 8 or 10-inch intervals and the resulting ring was split in two. To facilitate the examination, the halves were given a light pickle in hydrochloric acid to remove scale (and a thin copper film) and were then bent flat. The bending made examination under the binocular microscope easier and also served to open up any embrittled areas; mild steel which is not embrittled will withstand considerably more bending before showing minute rupture.

Figure 11 illustrates the type of specimen obtained and how readily the more severely embrittled steel is revealed in comparison with non-embrittled steel. In addition to the obviously cracked samples shown, many samples showed fine cracking when given detailed examination under the binocular microscope.

Using the method outlined above, an additional 17 random tubes from rows A to E of the failed boiler were examined. It was found that only tubes in A and B rows, of either side, showed intergranular cracking. The sampling was limited; nevertheless, the evidence available indicated that only some of the steam generating tubes, A and B rows, were damaged. Sound tubes were found next to cracked ones. In the defective tubes, the cracking was in a zone approximately centered at two to four feet from the top of the tubes; i. e. not too far from the bend which is approximately one and a half feet from the steam drum at the top.

Tubes from the other boilers on the ship also were examined by this method. Four tubes from each boiler, i. e., A-25 and B-25 from both left and right hand sides of each boiler, were sectioned at 8-inch intervals down to approximately five feet from the top. No cracking was detected in any of these tubes. Although this represents an inadequate sampling, it was not practical at the time to remove more.

Discussion of Results

From the microstructure examined, it was evident that tube A-25 and several other tubes had been severely weakened by intergranular cracking before final failure. This intergranular cracking had been initiated on the water side of the steam generating tubes and was most severe at a distance of between two feet to four feet from the top of the tubes.

Many metals and alloys are susceptible to intergranular cracking when they are in a stressed condition and in a specific corrosive environment. It should be emphasized that both stress and corrosive environment are necessary. The stress is often residual but may be a combination of residual and service stresses. The corrosive environment is usually such that in the absence of stress, the result would be a more or less uniform metal loss.

In the boiler tubes under discussion the stresses were the normal operating stresses resulting from steam generation at 400 psi and 650 F and the residual stresses. The high residual stresses from fabrication by extrusion and the local stresses from bending the tube would be relatively small after several years' operation, but would still be significant in relation to operating stresses.

The corrosive environment could only have been caustic from the boiler water. The caustic in this particular instance was by mistake at least twice the usual concentration. However, this increase is not considered too significant. It is true that the caustic concentration in boiler water is usually very low and is expressed in parts per million. However, very little

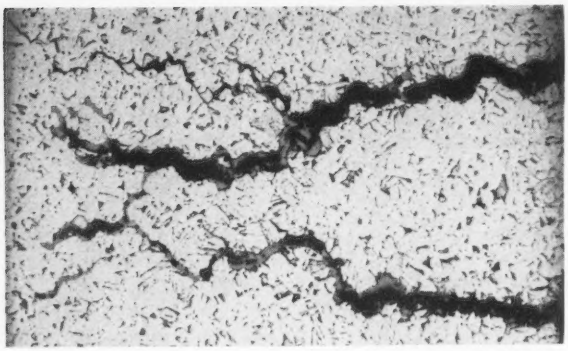

Figure 10—Photomicrograph of a section cut through the tube wall, B-39, showing detail of the intergranular cracking. Approx. 50x.

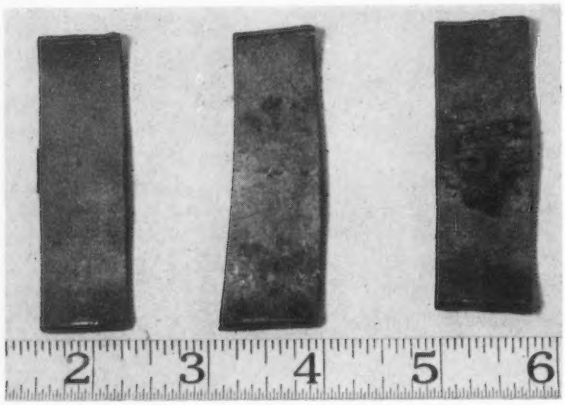

Figure 11—Slices cut from tube B-40 at (left to right): (1) an area which showed no cracking; (2) , (3) an area close to that shown in Figure 3, and bent flat.

over-heating is required to change the concentration in a film of water which is then measurable in percentage rather than ppm.[8] Local areas of "steam blanketing" are known to occur[8] when tubes are subjected to a high heat input, resulting in some increase in metal temperature and subsequent concentration of the caustic.

The intergranular attack which results from these conditions is commonly known as "caustic cracking." Although it is difficult to reproduce operating conditions in the laboratory, instances of cracking taking place in hours rather than days are recorded.[9,10]

Experiments by researchers investigating caustic cracking have shown that, "... the cumulative effect of a high rate of steam generation on a heat transfer surface may be equivalent to continuous exposure of the hot steel to a corrosive caustic liquor, even though the main body of boiler water contains but a few parts per million of hydroxide."[8] High rates of steam generation may not be usual in the RCN, but gas passages around the superheater tubes in Admiralty type boilers may be badly clogged with combustion products. It is conceivable that the net effect in uneven heat distribution would be equivalent to a high rate of steam generation for certain tubes. This clogging in the boiler was brought to our attention.

This local overheating could be expected to bring the caustic concentration to the point where it rapidly attacked the grain boundaries of the metal of certain tubes.

Evidence that such an assumption is warranted is contained in the way damage was confined to certain areas in a definitely haphazard manner, probably related to flow of hot gases subjected to irregular obstruction. In addition, the metallurgical evidence that the ruptured tubes had been heated above 1500 F and rapidly cooled, although not readily explained in terms of boiler operation, fits in with other investigators' findings on burst tubes.[2]

This same uneven heat distribution more than likely had two important functions aside from concentration of the caustic.

1. It tended to weaken the grain boundaries in relation to the remainder of the metal. It is a known fact that above a certain temperature for a specific metal, the grain boundaries are considerably weaker than the grains themselves; high temperature alloys often are purposely cast with large grains to minimize grain boundary area. This weakening of the grain boundaries would assist the preferential attack of the caustic.
2. It weakened the metal, so that the remaining ductile portion on the outside of tubes either burst or opened slightly.

Conditions for Caustic Cracking

From the evidence presented and from all the information available, it is considered this failure represents an example of the occurrence of stress-corrosion cracking, aside from that commonly occurring at riveted seams.

Lloyd's Register[11] reports some 162 ships suffered one or more boiler failures in the 15 years to 1950 and not once is failure described in terms other than that of a riveted seam. In fact, another official of Lloyd's Register has stated that "... no cases of caustic cracking in water tube boilers are on record."[12] As already indicated, this theme is repeated in much of the current literature.

Caustic cracking at riveted seams is fairly easily explained. In addition to the service stresses, the use of rivets results in a stressed state in the plate. The concentration of the caustic may be understood readily in terms of leakage and, thereby, a gradual increase in the concentration of salts. It is then a simple matter to have a combination of the necessary factors: stressed metal in contact with a concentrating solution of boiler water containing caustic.

When consideration is given to the attainment of similar conditions on the steam generating face of a water-tube, it seems advisable to examine in more detail the factors involved.

That stresses must be reasonably high, in fact close to the yield point, is commonly accepted.[4] However, other evidence in similar systems indicates that stresses of lower magnitude can and do cause intergranular cracking. The cracking of mild steel in boiling concentrated nitrate solution has a threshold stress of 14,000 psi[13] under certain conditions.

In discussing stress-corrosion cracking at low stress levels, it may also be pertinent to mention that cracking of 18.8 stainless steel has been initiated in boiling $MgCl_2$ solutions at stresses as low as 3000 to 10,000 psi[14] and this in a metal having a tensile strength at least 50 percent greater than mild steel.

There is, then, some evidence that stresses need not

approach the yield point of steel for stress-corrosion cracking to occur. It is not difficult to conceive of the existence of stresses sufficient to initiate cracking in the tubes under consideration.

The caustic concentration found necessary for the initiation of intergranular cracks varies considerably, presumably depending on stress level.

The study of boiler-seam cracking by the Joint Research Committee on Boiler Feedwater Studies and the U. S. Bureau of Mines, as reported by Berk and Waldeck,[15] indicates a danger zone above 180 F and between 15 and 43 percent caustic. The probability of crack development in this zone was 40 percent. Weir[16] reported failure of specimens exposed to solutions of less than 10 percent caustic, although he states that more concentrated solutions are more effective.

Both Copson[7] and Hamer and Colbeck[17] show in photomicrographs the similarity between cracking in boiler plate and in a mild steel which had been used in processing strong caustic solutions. The example cited by Copson was of an autoclave exposed to 50 percent caustic soda at 250 F and 400 psi.

Having shown that caustic concentrations upwards of 10 percent and probably upwards of 15 percent, are necessary before steel under stress will crack intergranularly, it remains only to show how such concentrations might be achieved. The caustic in boiler water is commonly* 200 parts per million ppm. This concentration is approximately 0.1 percent of that required for aggressive attack.

Hall[18] has ably presented the concept of a concentrating-film boiler water as opposed to the dilute overall boiler water. Hall has shown that alkalinity can readily increase from parts per million to parts per hundred when a hot spot occurs. The mechanism of concentration at billions of recurring water-steam interfaces may be considered similar to evaporation, in the process during which the concentrating-film boiler water seeks to establish equilibrium with its environment. At fixed pressure and with increasing temperature, the concentration of the salts in the film also increases.

That a hot spot can occur at a particular area on a tube is shown by Davidson and associates[19] who used thermocouples to study various conditions. Their measurements on a 50-foot tube showed a zone which was 200 F above the remainder of the tube. They considered this particular zone to represent steam-blanketing possibly caused by flame impingement. It may be pointed out that this condition reduced flow through the tube by almost 50 percent, a factor which undoubtedly would favor an aggravation of the local condition, i.e. steam-blanketing.

*RCN practice

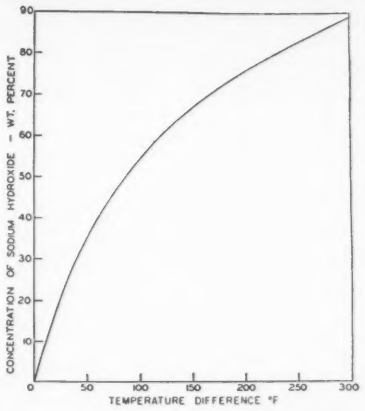

Figure 12—Graph showing how the concentration of caustic can increase when the temperature at the heat transfer surface goes above that of the main body of boiler water. Based on data from International Critical Tables, Vol. 3, 370 (1A28).

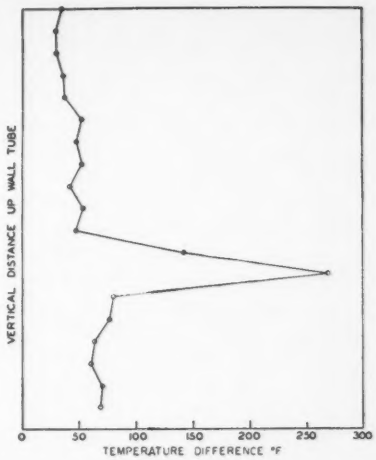

Figure 13—Plot of thermocouple measurements showing a region of severe overheating. This temperature rise on the outer surface of the boiler tube would correspond to a higher temperature at the heat-transfer surface on the inside of the tube.

The work of Hall[18] and of Davidson and associates[19] discussed above may be summed up in Figures 12 and 13 respectively. Figure 12 indicates how rapidly the caustic content in the concentrating-film boiler water can rise with a small increase of temperature above that of the over-all boiler water. A 100 F rise corresponds to 50 percent caustic in weight percent. Figure 13 shows that temperatures as high as 200 F above the main body of boiler water may be attained in the outer tube surface.

Study of this information would suggest that conditions leading to intergranular cracking of boiler tubes are possible. The possibility has been translated into an actuality by the failure here reported.

Mechanism of Caustic Cracking

In view of the many statements in the literature that the fundamentals of the caustic cracking phenomenon remain obscure, it may be instructive to assemble a few current ideas.

Zapffe's[1] strong argument that boiler embrittlement is an aspect of intergranular hydrogen attack and the consequent vigorous discussion sum up the current thought to that time. In the discussion to Zapffe's paper, Mears[20] advanced the opinion that caustic cracking and stress-corrosion cracking are fundamentally the same. The attack in stress-corrosion cracking is electrochemical, i. e., potential difference between anodic and cathodic areas of the metal causes electrochemical corrosion which appears in these instances, as cracking at grain boundaries. Mears indicated that the stress-corrosion cracking of Duraluminum-type alloys, the season-cracking of brass and the stress-corrosion cracking of 18-8 stainless steel had either been proven,[10] or indications were fairly definite, that the mechanism responsible for all was electrochemical differences in potential causing selective attack at certain planes in the metal. Mears suggested[20] that establishment of the mechanism of caustic cracking might be

readily undertaken by attempting to cathodically protect a readily-embrittled boiler steel. Investigating the effect of cathodic protection on cracking was also suggested by a leading technical committee.[21]

This confirmation of the true mechanism of caustic cracking has been reported. Pearson & Parkins[13] studying the stress-corrosion of mild steel subjected to boiling nitrates showed conclusively the electrochemical nature of the action. When a sample of the steel was made the anode in a system subject to 200 ma per sq. in., cracking was produced in one-thirtieth of the time (30 minutes vs. 15 hours) and was much more extensive than cracking in the absence of current. In no instance was cracking observed in the mild steel subject to the same conditions, but as the cathode instead of the anode.

Weir's[16] detailed study of the fundamentals of caustic cracking also has shown that anodic currents decrease time to failure (this was in 50 percent sodium hydroxide at 280 C) and that cathodic polarization is effective protection. Evans[22] quotes Edeleanu who "found that he could stop cracking at an advanced stage where the specimen was due to break within a few seconds, by applying a strong cathodic current."

It would appear logical, then, on the basis of the experimental proof cited above to include caustic cracking among the electrochemical corrosion phenomena known as stress-corrosion cracking.

The layer of copper which was noted on the inside of the tubes may have intensified the electrochemical action which is the basic mechanism. Suggested iron-copper reactions are described by Straub & Ongman[23] and copper in boilers is discussed in the Corrosion Handbook.[24]

Even with this understanding of the electrochemical nature of caustic cracking as a basis, it does not seem likely that a universal means of preventing it is at hand, aside from chemical treatment which avoids caustic.[25] Cathodic protection does not seem particularly feasible within tubes of a boiler.

Summary And Conclusions

An unusual type of failure of marine boiler tubes has been discussed.

It is considered the weakening of the tubes prior to the final burst (of tube A-25) and partial rupturing of several other tubes was due to caustic cracking.

Caustic cracking, a special case of stress-corrosion cracking, requires that the metal be subject to tensile stresses in a corrosive medium. It has been indicated that stresses of suitable magnitude were present and that conditions were such that the necessary concentration of caustic could be attained right on the steam generating surface of the tubes.

Research by others has shown that stress-corrosion cracking of metals is essentially electrochemical. Application of external current by these investigators has proven the electrochemical nature of stress-corrosion cracking. Samples which were made anodic were cracked extremely rapidly, whereas the cathodically protected samples could not be cracked.

Admittedly, the type of failure here discussed is rare, nevertheless, it can occur.

To prevent a recurrence of this type of failure, attention is being directed to avoiding clogging which can apparently channel hot gases. Some thought is also being given to alternative boiler treatments which avoid caustic.

Acknowledgment

The permission of the Defense Research Board to publish this paper is gratefully acknowledged. The co-operation of the Royal Canadian Navy and the valuable discussions held with several officers are appreciated.

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Corrosion by Valve Packing*

By L. M. RASMUSSEN

THE PROBLEM of stainless steel valve stem pitting has been found to be a condition of storage. When a valve has been assembled and hydrostatically pressure tested, the valve packing is saturated. Because a considerable period of time may elapse before the valve is put into service during this storage period corrosion in the form of pitting of the stem occurs. If the valve is put into service immediately after hydrostatic testing, there is no pitting.

Gardner and Donovan[1] have reported on corrosion of 12 percent chromium steel plungers and valve stems in the operation of a synthetic fuels demonstration plant. In this report, the pit corrosion was noted in the packing area after the units had been hydrostatically tested or had been in service and then placed in dead service. Pit corrosion in this case was attributed to bronze support rings or to copper in the braided packing. The same type of pit corrosion on 12 percent chromium steel in contact with pure asbestos yarn without copper or copper base alloy contact has been noted.

Soluble Constituents Contributory

Observations in the investigation of valve stem pitting showed that the presence of soluble corrosive constituents, such as magnesium and calcium chlorides, in asbestos base packings were major contributory factors. Potential measurements were made using various types of steel in an electrolyte prepared by leaching pure asbestos yarn in distilled water. Readings were taken over a period of five to eight months using a saturated calomel half cell. Figure 1 summarizes these data. The length of the box shows the maximum and minimum readings, the bar across the box is the average of all readings taken. There is no relation shown between the time and maximum and minimum readings. Economics of materials and manufacturing eliminated certain materials from consideration and it was therefore decided to investigate the possibility of obtaining packings treated to eliminate or reduce the corrosive constituents.

Various ideas were advanced on the type and method of treating packing to remove these constituents. It was deemed advisable to discuss these ideas with valve packing manufacturers in order to determine the practicability of such treatment and the problems arising therefrom in relation to packing manufacturing procedures. Arrangements were made with a packing manufacturer to discuss this problem.

The outcome of this meeting was a program formulated for the design of a non-corrosive packing as follows:

1. Reduction of chlorides and other objectionable water soluble salts by washing.
2. Elimination of chlorides from solution by precipitation.
3. Use of alkaline treatments to produce neutral to basic conditions.
4. Use of corrosion inhibiting salts.
5. Use of sacrificial elements, such as zinc, aluminum, etc.
6. The use of graphite and other dry lubricants of minimum corrosive potentials.

Method of Processing

Packings were prepared from braided stock consisting of two jackets of yarn over a wick prepared on a 24-carrier braider. Yarn analysis was 95 percent pure asbestos and 5 percent cotton with a similar wick or core. The braided stock was boiled in distilled water for four periods of three hours each using a water-to-braided stock ratio of 12:1 by weight. A sample of water after each boiling was analyzed to determine the solids and chlorides removed by such processing. As can be seen from the analytical results, Table 1, a substantial reduction of soluble chlorides in the braid must have been attained.

To precipitate the chlorides as a relatively insoluble salt a second batch of yarn was soaked for 24 hours in a 1 percent silver nitrate solution, rinsed

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Abstract

The result of observations in the investigation of valve stem pitting during storage after hydrostatic testing was that the presence of soluble corrosive agents in the asbestos braid and graphite lubricant were responsible for the condition. Various packing treatments, graphites, sacrificial elements and inhibitors were formulated or chosen and tests conducted at three locations using Type 416 stem material. Test results indicate that removal of soluble corrosive constituents, incorporation of inhibitors or sacrificial elements and careful selection of graphite dry lubricant in the packing manufacture are beneficial and necessary.

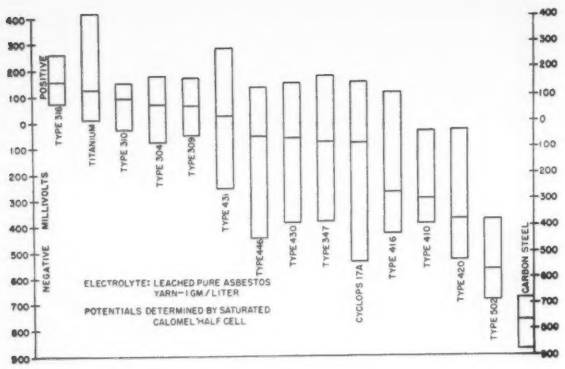


Figure 1—Galvanic potential rating of valve stem materials.

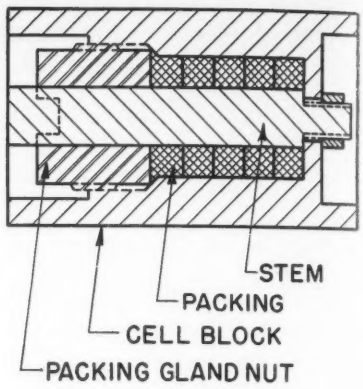


Figure 2—Packing test cell.

and soaked in distilled water over night. Further samples were prepared by soaking in a 10 percent solution of trisodium phosphate; zinc chromate slurry and sodium chromate slurry. As a lubricant for the packing, white mineral oil was used and the packing soaked for one hour at 200 F. Dry lubricants were applied by rolling the packing in the lubricant until well covered. Metal powders were applied by rolling the packing in a mixture of 75 percent dry lubricant and 25 percent metal powder by volume.

TABLE I—Wash Water Analysis

	Total Solids PPM	Chloride as Cl. PPM
First Wash	223	70
Second Wash	90	27
Third Wash	57	12
Fourth Wash	42	6

TABLE 2—Packing Makeup Chart

Packing No.	Wash	Silver Nitrate	Tri-sodium Phos-phate	Neutral Oil	Dry Lubricant	Sacrifical Element
1-C						
1-1	X			X		
1-2	X	X		X		
1-3	X		X	X		
1-4			X	X		
1-5				X		
1-6	X					
1-7	X	X				
1-8	X		X			
1-9			X			
1-10		X				
2-1	X			X	Dixon 200-8	
2-2				2X	Dixon 200-8	
3-1				X	Dixon 1122	
3-2				X	Asbury Madagascar JM No. 2	
3-3				X	Asbury 90-7	
3-4				X	U. S. Mexican 16	
3-5				X	Dixon 1108	
3-6				X	U. S. Karbonaro 54	
3-7				X	Dixon 1117	
3-8				X	Southwestern 1635	
3-9				X	Mica. Water-ground	
3-10				X	Bentonite Clay	
4-1				X	Dixon 1117	Zinc Powder
4-2				X	Dixon 1117	Cadmium Powder
4-3				X	Dixon 1117	Aluminum Powder
4-4				X	Dixon 1117	*Aluminum Powder
4-5				X	Dixon 1117	Zinc Washer
4-6				X	Dixon 1117	Cadmium Washer
4-7				X	Dixon 1117	Aluminum Washer
5-1			Zinc Chro-mate	X	Dixon 1117	
5-2			Sodium Chromate	X	Dixon 1117	

* Treated to Remove Stearate.

All packings were calendered to 3/8-inch square across section. Table 2 shows the packing make up chart.

Test Cells Simulated Valve Conditions

Test cells were used wherein the packing zone was equivalent to that of a standard valve. Figure 2 shows a cross section sketch of the type of cell and assembly used. Stem material for the test was AISI Type 416 steel having a surface finish of 11 to 16 micro inches. The packing in the test cells was saturated by allowing distilled or tap water to flow through the cell under pressure and then tightening the packing gland to 150 foot pound torque and hydrostatically testing at 1000 psi. Three cells were used for each packing. The cells were stored at room temperature and the recess filled with water for one week and allowed to remain dry for one week alternating for the entire period of the test. The same water as used for hydrostatic testing was used for saturating the cells. Cells 1 and 3 were opened, examined and rated after each 30 days of test and reassembled for three test periods. All cells were dismantled, examined and rated after 120 days.

Stems were examined with a 10X glass and rated according to the arbitrary corrosion ratings shown in Table 3.

At two test locations demineralized water was used in place of distilled water and electrometric readings indicated that contaminants were present in the order of 0.2 to 0.5 ppm. An analysis of the tap water used for test was obtained and a comparison is shown in Table 4.

Test Results Analyzed

Examination of the test stems was made every 30 days for a period of 120 days and on one test stem for an uninterrupted test period of 120 days.

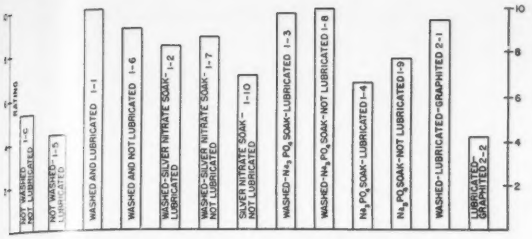


Figure 3—Effect of washing, lubrication and graphite on corrosion of Type 416 stainless steel valve stems under asbestos packing.

In analyzing the test results, the packings have been grouped according to the treatment given or variations thereof as noted in the packing make-up chart of Table 2. Figure 3 shows an analysis of the first and second groups.

Packing 1C — unwashed and not lubricated.
Packing 1-5 — unwashed and lubricated.

Since the only difference in these packings is in lubrication, results would show the effect, if any, of the lubricant. Test results indicate that the lubricant selected was relatively non-reactive or non-corrosive.

Packing 1-1 washed and lubricated.
Packing 1-6 washed and not lubricated.

The probable beneficial effect of washing is seen in the results of tests with these packings when compared to the preceding group.

Packing 1-2 washed, silver nitrate soak, lubricated.
Packing 1-7 washed, silver nitrate soak, not lubricated.

The packings are similar to 1-1 and 1-6 except for the additional operation of the silver nitrate treatment. The packings have a good rating but are definitely not as good as the 1-1 and 1-6 packings as shown by the ratings at two of the test locations.

Packing 1-3 washed, trisodium phosphate soak, lubricated.
Packing 1-8 washed, trisodium phosphate soak, not lubricated.

No appreciable difference in ratings was obtained for these packings and the additional phosphate soak did not appear to provide any additional protection.

Packing 1-4 trisodium phosphate soak, lubricated.
Packing 1-9 trisodium phosphate soak, not lubricated.

In general, the ratings on these packings were lower than those obtained on the washed packings and it would appear that this treatment is not as effective as the washing treatment.

Packing 1-10 silvate nitrate soak, not lubricated.

This treatment, while providing some protection, was not as effective as some of the other treatments.

The second group of packings, while experimentally produced, is probably the closest to the regular type of commercial packing used than any others in

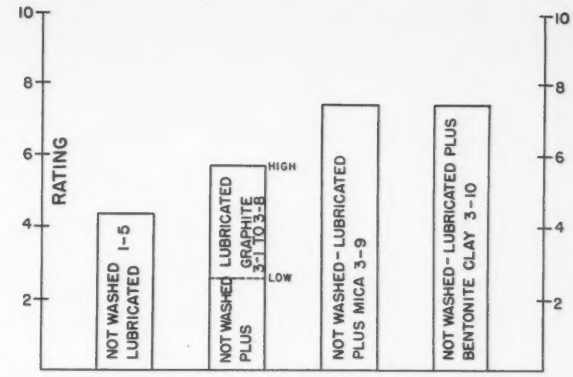


Figure 4—Effects of graphite, mica and Bentonite clay on corrosion of Type 416 stainless steel valve stems under asbestos packing.

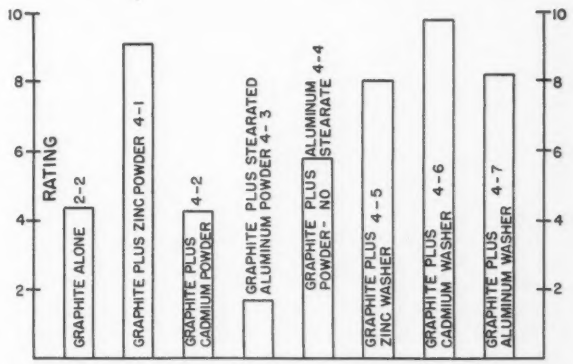


Figure 5—Effect of galvanic anodes on corrosion of Type 416 stainless steel under unwashed lubricated asbestos packing.

TABLE 3—Arbitrary Corrosion Rating

Rating Number	Percent Area Corroded in ½" Dia. Circle (0.2 Sq. In.)
10	0.0
9	0.01— 0.10
8	0.11— 0.25
7	0.26— 0.50
6	0.51— 1.00
5	1.01— 2.50
4	2.51— 5.00
3	6.00— 10.00
2	11.00— 25.00
1	26.00— 50.00
0	51.00—100.00

TABLE 4—Tap Water Analysis

	Stratford	Manville	Watertown
Color PPM	12–32	0.0	8.0
Odor	Variable	0.0	
Turbidity PPM	0–5	0.0	0.5
Temperature F	37–72		35–37
Chloride	4.98–8.10	8.0–13.0	2.6
Albuminoid Ammonia	0– .65		
Free Ammonia	0– .005		
Nitrate	0– .06		
Nitrate	.05– .27		0.15
Total Hardness as:			
Ca CO3	15–32	64–140	5.4
Alkalinity as:			
Ca CO3	8.5–20	42–54	11.0
Free CO3	—9.3		2.4
Dissolved Oxygen	6.7–13.4		13.5
pH	6.9–7.5	6.2–6.5	6.7
Total Solids	39–82	112–215	20
Fixed Solids	20–61		18
Iron—Total	.06–1.27	.1–.2	.02
Sulfates	10.04		3.0

this investigation. This group consists of two samples only, the first of which was washed, oil lubricated and had a dry graphite lubricant.* The second, with the exception of the washing treatment, was the same as the first. Results at one test location showed a definite advantage to the use of a packing treatment.

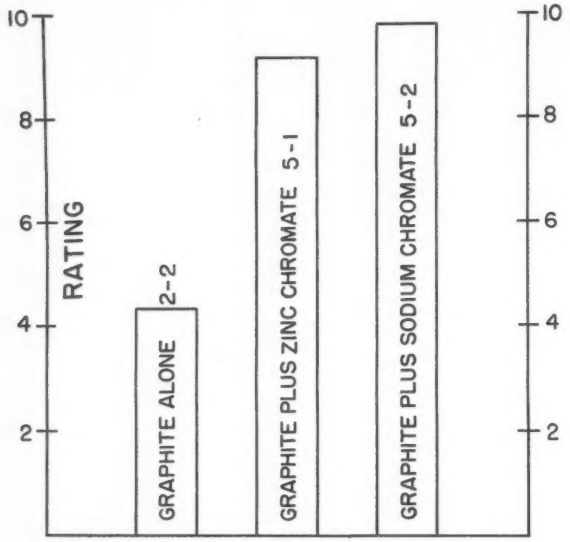


Figure 6—Effect of chromate inhibitors on corrosion of Type 416 stainless steel under unwashed, lubricated, graphited asbestos packing.

An analysis of test results of the third group of packings is shown in Figure 4.

In this group, various grades of graphite, a water ground mica and a bentonite clay as dry lubricants were compared using untreated, lubricated braid. In order to analyze this group, results should be compared with packing 1-5 which was similar in all respects except that it did not have a dry lubricant. Some indication of the effects of various grades of graphite can be seen from the results obtained.

An analysis of the group 4 packing test results is shown in Figure 5.

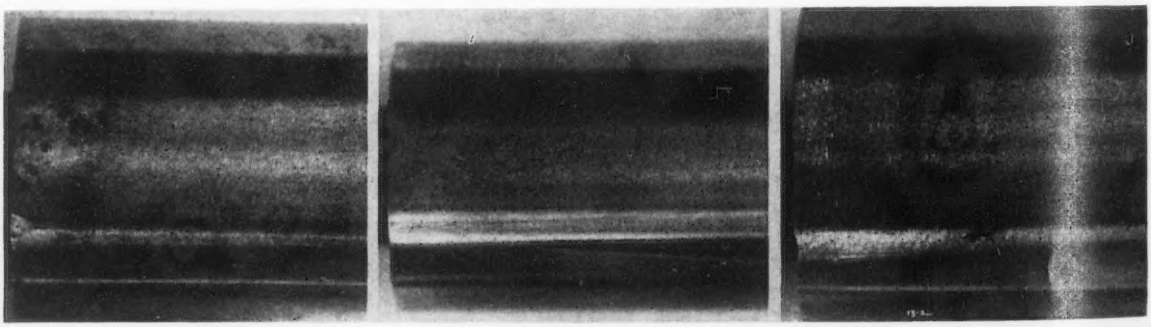
Sacrificial Metal Tested

This group consisted of unwashed, oil lubricated braided packing with graphite† as a dry lubricant and a sacrificial metal or metal powder in their construction or assembly. The aluminum powder in packing 4-4 had had the stearate removed prior to use, packing 4-3 was the same except that the stearates had not been removed. The effectiveness of sacrificial metals can be seen from the results obtained.

Analysis of the group 5 packing test results is shown in Figure 6.

This group is similar to the group 4 packings except that zinc chromate and sodium chromate inhib-

* Dixon 200-8.
† Dixon 1117



Tap Water | Distilled Water | Demineralized Water

Figure 7—Stem corrosion with packing designation 1-7.

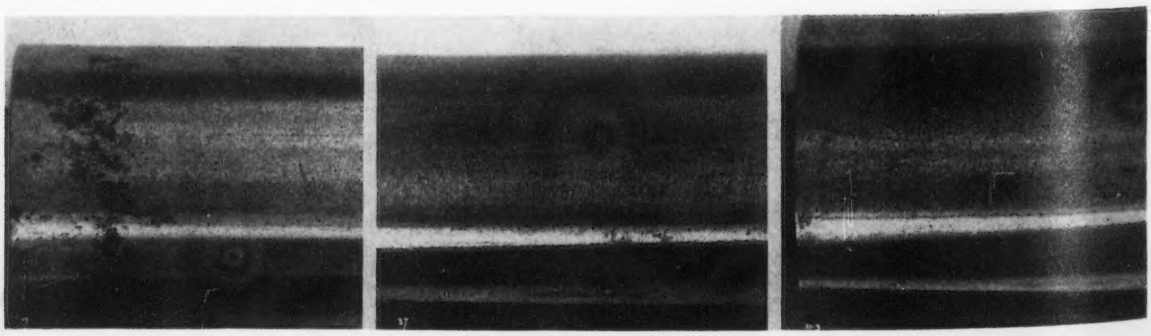


Figure 8—Stem corrosion with packing designation 2-2 in tap water.

itors were used instead of a sacrificial metal. There seems to be little difference in these materials, however, results do favor the sodium chromate which would be more economical material than the zinc chromate.

Value of Treatment Substantiated

The test results appear to substantiate the idea that a treatment to remove or inactivate the soluble corrosive constituents of asbestos base valve packing is necessary to eliminate or substantially reduce the pitting of valve stem material. Some differences were noted in the results at the test locations. However, consideration should be given to the measurement of the corroded area wherein the difference between ratings of 10 to 5 is 0 to 0.005 square inches or up to ¼ of 1 percent of the area under examination. An accurate determination of the extent of the corrosion in the small area involved by the method used would be extremely difficult and might account for the differences noted in the test results.

Some difference in the corrosiveness of various grades of graphite was shown in the third group of this investigation which indicates that if the asbestos packing is untreated care should be taken in the selection of graphite used.

Natural Graphite Reactive

Natural graphite contains mineral matter sometimes amounting to 14 percent by weight as determined in the ash. The mineral matter, intimately associated with the mined graphite, generally contains considerable amounts of iron compounds in the forms of magnetite, hematite, limonite, pyrite and pyrrhotite.

The use of natural graphite in packings of this type is prone to produce continual corrosion due to the slow conversion and oxidation of the pyrite into aggressive compounds. The examination of a water solution of the graphtie reveals nothing of the high degree of reactivity of certain of the natural graphites in the presence of ferric salts to cause corrosion.

Artificial Graphite May Be Better

Artificial graphite is non-magnetic, but the presence of both magnetic and pyrrhotite in natural graphite render this material magnetic. The higher luster of artificial graphite is due to the absence of the mineral matter present in the natural graphite. It appears that artificial graphite would not be as corrosive to steel as the natural graphite due to the absence of mineral matter.

Metals and Inhibitors Beneficial

Results with sacrificial metals and chromate type inhibitors incorporated in untreated packing show that benefits can be realized through their use. At the high operating temperatures ranging from 750 F to 1050 F and with the present trend to still higher operating temperatures the sacrificial metals and chromates which might be incorporated in the packing would be in a molten state. Normally, these materials possess good anti-corrosive properties, but very little data are available on their corrosive effect on steel at elevated temperatures.

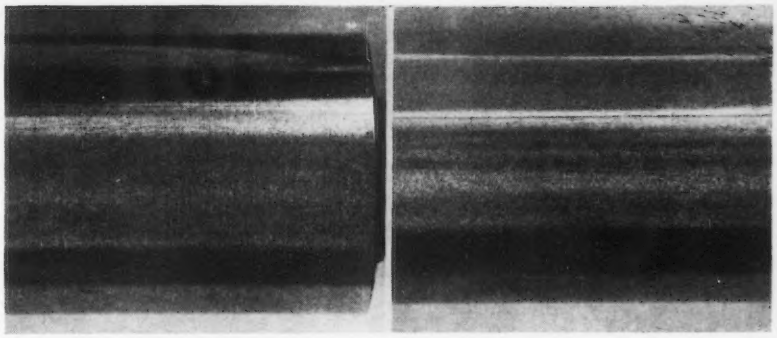


Figure 9—Stem corrosion with packing designation 5-2 in tap water.

All test stems used were of AISI Type 416 stainless steel, photographs representatives of tests results from various packing formations are shown. Each stem in the following groups is from a different test location using the same type packing after 120 days of test.

Packing Designation 1-7: Washed, silver nitrate soak and not lubricated.

Figure 7 shows stem numbers 58, 24 and 13-2. Test water was tap, distilled and demineralized water, stem ratings were 5, 10 and 7 respectively.

Packing 2-2: Unwashed, dry graphite lubricant and oil lubricated.

Figure 8 shows stem numbers 17, 37 and 21-3 having ratings of 2, 4 and 10 respectively after exposure to packing saturated with tap water for 120 days.

Packing 5-2: Unwashed, sodium chromate inhibitor, graphited and oil lubricated.

Figure 9 shows stem numbers 1 and 85 having a rating of 10 after 120 days' exposure to packing saturated with tap water.

Packing Specifications Needed

While results were not in complete agreement, it appears that treated packings are less corrosive than untreated packing. Since the inception of this investigation the use of inhibited or otherwise treated packings has been promoted more than previously. The only known specification for packing, metallic and non-metallic, or plastic is 33P-25C of the Navy Department. This specification covers the general packing construction and tests but does not control the asbestos, graphite or binder except in a general manner. There is a definite need in the valve and pump industry for a packing specification to limit or control the corrosive agents present as well as the performance characteristics.

Conclusions

The following conclusions can be drawn from the results of this investigation.

1. A packing treatment to remove soluble corrosive constituents or to include inhibitors is beneficial in eliminating or retarding the corrosion of valve stems.

2. The choice of graphite is important but its importance may be reduced by the use of a packing treatment.

3. Certain sacrificial metals included in the packing construction are beneficial.

Acknowledgments

The writer is grateful to the management of Manning, Maxwell & Moore for permission to publish this work; to M. K. Cumming, R. T. Halstead, H. G. Koch and A. H. Jenssen of Johns Manville Research Center for their assistance in formulating the test program, production of the packing and conducting tests; L. M. Burrows and M. W. Eastman of Manning, Maxwell & Moore, Watertown Plant, for their assistance; A. D. Eplett, Technical Director of Manning, Maxwell & Moore, for his advice, assistance and guidance in this investigation.

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Electrolytic Descaling*

An Electrical Method of Rust Removal From Tanker Ship Compartments

By F. E. COOK, H. S. PREISER and J. F. MILLS

Section 1—Introduction and Discussion

Application of Method

IN ALMOST every engineering application involving the use of ferrous materials, the problem of rust removal is forever present. The effectivenes of the paint and preservation of steel requires a clean, rust-free surface for optimum performance. Clean rubbing surfaces between the steel components of machinery is necessary to insure its uninterrupted operation. When steel containers are reused for storing various fuels or other liquids and chemicals, often rust must be removed to prevent contamination. In the past, chemical, mechanical and thermal methods have been employed for cleaning rust from steel and in many cases they proved to be costly and not entirely effective. In recent years a great deal of effort has been expended by government and industry to produce an economical and efficient electrolytic descaling technique. This method is gradually receiving widespread consideration for the cleaning of relatively small objects as evidenced by several commercial processes available on the American and British markets.[1]

The fact that electrolytic descaling can be accomplished by immersing small metallic articles in tanks containing the electrolyte or by immersing larger components directly in the sea or by filling the tank, cylinder or container to be cleaned with the electrolyte, allows a wide diversity in the type of equipment which can be cleaned by this process. The British Admiralty has successfully applied electrolytic descaling techniques to the cleaning of a high pressure turbine, a badly rusted internal combustion engine, boom defense equipment, a superheater header and a variety of other equipment. A summary of the British work has been effectively covered in the literature.[2]

The various electrolytic descaling processes available do not differ in their essential elements but only in minor modifications. The theory involved is relatively simple. However, the engineering necessary to apply this theory effectively to large surfaces and complex structures in situ, is a problem of considerable magnitude. This paper will be confined mainly to efforts of the Bureau of Ships to descale and clean tanker ship compartments of U. S. Naval vessels.

Description of the Process

The ability of a properly applied electric current to remove rust from metals has been known for the past several decades. Numerous patents have been filed describing different ways of derusting and descaling metals by electric means.[3, 4, 5, 6, 7]

Basically the electrolytic method of derusting metals requires that the material or object being cleaned of rust, be completely immersed in, or surrounded by, an electrolyte of sufficient conductivity to carry and distribute the electric current needed for the derusting process. For marine purposes on a large scale, seawater appears to be most convenient and adaptable for use as an electrolyte; however, the electrolyte may well be a solution of any of several salts, acids or bases.

There are two ways in which cleaning can be accomplished, one in which the object being cleaned

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Abstract

A detailed report of the theory, technique and application of electrolytic derusting to the cargo tanks of United States Navy tankships. After a discussion of the various aspects of anodic and cathodic cleaning of rust from steels, the theory of the process, together with an account of patents, army use of the method and initial navy testing and applications is reviewed.

Details of the laboratory investigations preceding the application of the descaling method are given, including apparatus and materials. Effects of anode spacing, electrolyte composition, temperature, effect on faying surfaces and on dissimilar metals (aluminum, zinc, lead and brass), additions of sulfuric acid to electrolyte, current reversals, detergents, hydrogen embrittlement are surveyed. Results using anodes of magnesium, aluminum, zinc, copper and platinum are reported. Volume of gases given off by the various anodes is measured.

Reports on the electrolytic descaling of nine vessels are given, including an estimate of the final tank conditions, optimum current density, anode area, current distribution, washing down operations, intermittent flushing, hydrogen evolution and cost comparisons with conventional cleaning methods. Specific recommendations and an account of the practical details involved in the procedure are given. 15 tables, 33 figures.

is made the anode, and the other in which the object being cleaned is made the cathode. Anodic cleaning is rapid and is capable of leaving the metal in a bright smooth condition. When used as the sole method of cleaning objects that are heavily corroded, severe etching or pitting may occur. However, it has been found that a caustic soda solution (less than 5% by weight), used as an electrolyte will liberate oxygen at a steel anode instead of dissolving the anodic metal itself. In general, except for superficial cleaning and electropolishing, the object to be cleaned is seldom made the anode in the electrolytic derusting process. Most commercial electro-cleaning methods use combinations of anodic and cathodic cleaning. The additional baths employed in commercial cleaning processes usually consist of degreasing agents, emulsifiers and wetting agents, rinsing baths and temporary anti-corrosive treatments, after descaling is complete. In order to improve the appearance of an article, when it is cleaned cathodically, cyanides are sometimes added to caustic solutions and the article is given a short reversal of current, (anodic) as the last step in the descaling process.

In cathodic cleaning, the object being cleaned is made the cathode in the electrolytic circuit thereby eliminating the danger of damaging the object through etching and pitting. The principles that apply to cathodic protection also apply to this method; the major differences being that the current density for electrolytic cleaning is generally about 100 times greater or more. Cathodic cleaning is the only electrolytic process that can be safely employed in a sea water electrolyte. Aside from the inherent advantage of electrically protecting the article to be cleaned, the process is free of noise and dust. There is no mechanical or thermal abuse of the metal and lastly the process is economically competitive.

Limitations of the Process

Since no single process can be considered a panacea for unlimited application, some of its limitations should be borne in mind. Tightly adherent mill scale is a rather good conductor of electricity and generally non-permeable to the penetration of sea water. As such, electrolytic descaling is not effective in removing mill scale from steel surfaces. Aluminum and lead fittings will generally be atacked due to the alkaline reaction at the cathode (cathodic corrosion) and therefore should be masked or removed from the electrolyte during electrolytic derusting. Further, the cathodic process usually involves the evolution of hydrogen from the cathode. This is a constant source of danger when descaling operations are performed in confined spaces. Lastly, although mild steel does not exhibit tendencies of hydrogen embrittlement when subjected to cathodic cleaning, certain high tensile steel and stainless steels may become embrittled and therefore would require further treatment to restore their ductility.

In the cathodic cleaning process, the electrode functioning as the anode may be one of several materials. Graphite anodes and steel shapes, usually in the form of rods, angles and plates have been used successfully. Scrap metal can be utilized in order to keep costs to a minimum. High silicon iron is being investigated as a possible low cost insoluble anode. The positive terminal of a direct current power supply is connected to the anode through a rheostat of suitable resistance and the negative terminal of the power supply is connected to the object being cleaned.

Theory of Electrolytic Derusting

When steel is placed in an electrolyte as the cathode and an ample electric current is allowed to flow, a reducing action occurs on the metal surface. Hydrogen ions attracted to the surface of a clean steel cathode are converted to a layer of hydrogen atoms which increase the steel electrode potential in the anodic direction. This phenomenon is known as polarization. The applied voltage needed to drive the required current during the descaling process causes the potential on the clean portions of the steel cathode to be raised above its hydrogen overvoltage level which results in the liberation of hydrogen gas. Under these conditions substantially no corrosion can occur.

If the steel surface is rusty, this reducing action at the cathode converts some of the ferric oxides or hydroxides to the ferrous form.[8,9,10] These chemical changes weaken the rust scale and permit its separation from the metal by virtue of its own weight. Any loosely adherent scale that remains can be removed readily by hosing down with water under pressure or by hand scraping. The chemical reactions associated with electrolytic rust removal will vary somewhat depending upon the nature of the electrolyte.

The Cox Process—The early work of Cox,[12,13,14,15,16] dealing with electrolytic methods of descaling and electrocoating rusted and badly fouled steel plates led to extensive investigation by the Bureau of Ships several years later of the practical application of this process to the descaling of cargo tank compartments of Navy oilers. Since the Navy was primarily interested in restoring rusted steel to its original clean bare condition and not in coating the steel with calcareous deposits, some modification of the original

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process resulted. The details of the Cox process were worked out during World War II but conditions at that time did not permit extensive investigation for naval use. However, the descaling phase of the process was considered sufficiently advantageous from the viewpoint of saving time and manpower, that general instructions were prepared by the Bureau of Ships in 1943 authorizing the removal of rust from cargo tanks of Navy oilers in gasoline service by this electrolytic method. Even so the process was not tried in the Navy until several years after the war.

Toward the end of World War II, the Army Transportation Corps became very active in developing suitable procedures for electrolytic defouling, descaling and electro-coating ship hulls and tanker compartments. Since a great deal of Army marine transport was on active duty overseas, the work was performed at Transportation Corps Headquarters, 14th Port, United Kingdom Base, Southampton, England.[17]

The Army work aroused British interest and as a result, several independent investigations were made by the Admiralty Corrosion Committee covering theoretical and practical considerations of electrolytic descaling. In 1947, the Army authorized Newport News Shipbuilding and Drydock Company to outfit the FS212, a freight and supply vessel, with special equipment to serve as a floating laboratory for the large scale testing of all aspects of the electrolytic process. The results of this extensive project are summarized in a final report.[8] Several additional patents were issued to Colonel G. C. Cox at the completion of these studies.[18,19,20,21,22] A more recent account of the electrolytic descaling work which was undertaken by Newport News Shipbuilding and Drydock Company was presented at the annual meeting of the Society of Naval Architects and Marine Engineers in 1953.[23]

Initiation of Test Work

The need for an improved cleaning process for tanker cargo tanks became acute during the latter part of 1947 and early 1948, as a result of the tanker reactivation program. It was therefore decided to conduct an experimental full scale trial of the electrolytic cleaning method on the cargo tanks of the USS *Cimarron* (AO22) at the San Francisco Naval Shipyard. The results of this trial were sufficiently promising to warrant additional experimentation.[10] Early in 1948, Puget Sound Naval Shipyard developed improved electrodes and utilized a system providing much higher current densities than previously used.

In 1948, a project was established at the Material Laboratory of the New York Naval Shipyard for the investigation of the many variables and principle significant factors involved, in the derusting of steel surfaces by cathodic treatment with and without the formation of the calcareous deposit. The highlights of these studies are described in Section 2 of the paper.

Prior to and concurrent with the laboratory work at the New York Naval Shipyard, Puget Sound Naval Shipyard proceeded with experimental service trials of cleaning Navy oilers by the electrolytic method as these ships became available in the course of normal yard schedules. The results of the work at both shipyards were reported frequently to each other and to the bureau. This insured the incorporation of current developments into the program as the work developed. Section 3 of the paper elaborates on the practical methods developed by the Puget Sound Naval Shipyard. Charleston and Pearl Harbor Naval Shipyards also descaled cargo tanker compartments of two naval oilers by methods similar to those developed at Puget Sound.

Section 2—Laboratory Investigations*

Objective—The objective of this investigation was to experimentally explore the field of electrolytic derusting as applicable to flat, plain ferrous surfaces and as part of the final objective to be able to derust or clean any metallic surface regardless of its geometric configuration.

Apparatus and Materials

Specimens—The steel specimens used as the cathode in the majority of the experiments were cut from a large, previously unused sheet of structural steel plate, ⅛ inch thick. This steel plate conformed to Type A, Grade M of Bureau of Ships Specification 4885(INT) of 1 November 1944. It was covered with a rather uniform layer of mill-scale. Specimens were cut to the desired size as follows:

1. Specimens requiring mill-scale on their surfaces were not subjected to any special treatment.
2. Specimens requiring uniformly rusted surfaces were first treated for removal of mill-scale by a pickling operation and then rusted over a three-week period. The rusting operation consisted of immersing the specimens for a five-second period twice daily in water containing three percent of sodium chloride. The immersion periods were at time 8 am. and 4 pm. for five consecutive days per week and during the intervening drying periods the specimens were separated and suspended in air at the ambient temperature of 70 degrees F.
3. Specimens requiring painted surfaces were first treated for removal of mill scale, rinsed and washed in fresh water, dried at temperature of 70 degrees F. and then painted as described later.

Steel cathode specimens were used unless otherwise specified and all current densities are computed on the inner surface area facing the anode.

Anode materials were pieces of ¼ inch diameter mild steel welding rod or strips of the ⅛ inch thickness structural plate unless other metals are specifically noted.

Electrolytes—The electrolytes were as follows:

1. Sodium chloride solutions of various concentrations, prepared by mixing reagent grade sodium chloride and distilled water.
2. Synthetic sea water, prepared from distilled water and chemicals, in following proportions:

Material	Grams per liter of water
sodium chloride	23.00
potassium sulfate	.85
calcium sulfate	1.30
magnesium chloride	3.40
sodium bromide	.050
sodium iodide	.005
silica	.015

* Adapted from New York Naval Shipyard Final Report 5902 "Electrolytic Derusting of Metals" of 14 June 1950.

3. Detergents as noted were added to the electrolyte in certain experiments.

Equipment—The containers to hold the electrolyte and anodes were either glass beakers, hard rubber battery cases or wooden tanks of the required size, as later descrbide.

The direct current power supply for the experiments was obtained from Navy standard portable storage batteries, usually class 6V-SMBD-130AH of Navy Department Specification 17B4h.

Rheostats for regulating current supply were the stepless control carbon pile type, with resistance up to 100 ohms and dissipating capacity of 750 watts per unit.

Electrical instruments of suitable range were used to measure direct currents from 25 milliamperes to 10 amperes and voltages up to 20 volts.

The electrolyte solutions were checked for pH by means of the Beckman pH meter.

Tensile strength specimens were pulled for strength and elongation on a standard tensile strength machine. Specimens for flexural strength tests were tested on a suitable machine.

Procedures, Results and Discussions

In the initial phase of these experiments the anode was a single piece of steel welding rod the same length as, and mounted paralled to the vertical centerline of the rusted steel plate which served as the cathode (unless otherwise noted). Except for comparison of results obtained using synthetic seawater, the electrolyte was 3 percent sodium chloride solution.

Effect of Cathode Current Density on Time and Efficacy of Rust Removal

The experiments were made under identical conditions except that cathode current density ranged from 0.10 to 1.00 ampere per square foot of cathode surface area. Periodic readings were taken on voltage required to maintain the desired cathode current density and the specimens were examined at intervals in order to obtain information on progress of the derusting operation. The experiments were stopped over night, as necessary, and discontinued when the specimens were free of rust.

The data plotted in Figure 1 indicate that the rate of electrolytic derusting of steel is nearly directly proportional to cathode current densities greater than ¼ ampere per square foot, other factors being equal. When the current density is increased to the order of 1.0 ampere per square foot the cathode gases vigorously and is cleaned in what appears to be a proportionally shorter time.

Figure 2 contains the data from another series of experiments in which the cathode was 22 inches in width and the electrode spacing was only 6 inches. Under these conditions derusting is not directly proportional to cathode current density within the same range shown in Figure 1. Apparently the electrode spacing was inadequate to give the anode sufficient throwing power to effectively cover the 22 inch width of the cathode. Electrode throwing power is covered by a later paragraph.

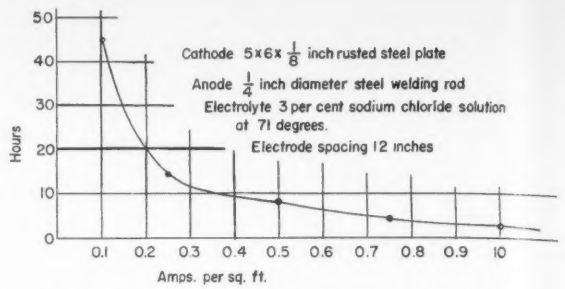
Cathode 5x6x ⅛ inch rusted steel plate
Anode ¼ inch diameter steel welding rod
Electrolyte 3 per cent sodium chloride solution at 71 degrees.
Electrode spacing 12 inches
Hours
Amps. per sq. ft.

Figure 1—Cathode current density vs derusting rate of steel plates.

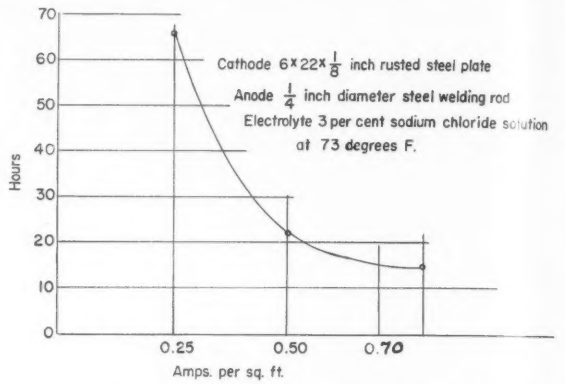
Cathode 6x22x ⅛ inch rusted steel plate
Anode ¼ inch diameter steel welding rod
Electrolyte 3 per cent sodium chloride solution at 73 degrees F.
Hours
Amps. per sq. ft.

Figure 2—Cathode current density vs derusting rate of steel plates.

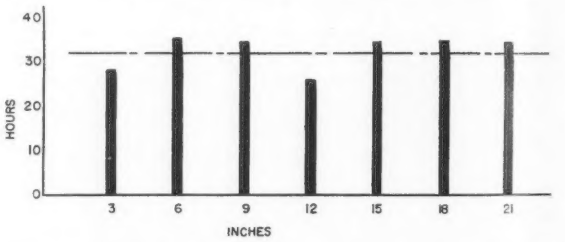

Figure 3—Electrode spacing vs time required for derusting steel plates. Cathodes 5x6x⅛ inch rusted steel plate. Anodes ¼ inch diameter steel welding rod. Electrolyte 3 percent sodium chloride solution at 70 F. Cathode current density 0.25 ampere per square foot.

The current required for a large scale derusting operation makes it generally mandatory to use as low a cathode current density as will insure completion of the derusting operation with a reasonable period of time. This consideration would normally limit cathode current density within the range of from 0.25 to 0.50 ampere per square foot of cathode surface area. Cathode current densities appreciably lower than 0.25 ampere per square foot are not advisable when the time element is an important consideration. Cathode current densities higher than 0.50 ampere per square foot normally are not necessary or may not be advisable because of additional factors involved such as gas evolution and possibility of hydrogen embrittlement of the cathode metal.

Effect of Spacing Between Electrodes on Time Required for Derusting

These experiments were run under identical conditions except that spacing between cathode and anode

TABLE 1—Removal of Mill Scale On Steel Plates

Cathodes 5 x 6 x ⅛ and 6 x 22 x ⅛ inch steel plates with mill scale anodes ¼ inch diameter steel welding rods. Electrolyte 3 percent sodium chloride solution at 71 F.

Cathode Size Inches	Cathode Current Density Amp./ Sq. Ft.	Electrode Spacing Inches	Potential Between Electrodes Volts	Derusting Time Hours	Mill Scale Removal Percent
6 x 22	0.25	5.0	1.04	0	
	0.25	5.0	1.12	7	None
	0.25	5.0	1.01	14	None
	0.25	5.0	0.99	21*	None
	0.25	5.0	1.03	33	None
5 x 6	0.48	2.5	0.63	0	
	0.48	2.5	.69	7	None
	0.48	2.5	.68	22†	None
	0.48	2.5	.69	51	None
	0.96	2.5	.95	51	None
	0.96	2.5	.87	65	None
	1.44	2.5	1.15	65	None
	1.44	2.5	1.09	72	None
5 x 6	0.96	2.5	0.88	0	
	0.96	2.5	.91	7	None
	0.96	2.5	.91	14	None
	0.96	2.5	.93	22	None
6 x 22	0.50	5.0	1.10	0	
	0.50	5.0	1.22	6	None
	0.50	5.0	1.25	12	None
	0.50	5.0	1.27	19	None
6 x 22	0.75	5.0	1.67	0	
	0.75	5.0	1.56	7	None
	0.75	5.0	1.53	13	None

* Current reversed every 2 hours during last 12 hours.
† Current reversed periodically after 22nd hour.
In experiments 3 and 4, two cathodes were used, with only one anode.

was different in each case, ranging from 3 inches to 21 inches in steps of 3 inches. Voltage data and condition of cathodes were recorded periodically. Operations were discontinued over night, as necessary and stopped upon complete removal of rust from specimens.

The data illustrated in Figure 3 indicate that electrode spacing, within the limits tested, does not affect derusting time. The variations which do exist in this data are not considered significant.

Effect of Spacing Between Electrodes on Potential Required to Maintain a Given Cathode Current Density

Several experiments were run with electrode spacing progressively changed from 1 foot to 10 feet. Cathode current densities were 0.75 and 3.30 amperes per square foot of cathode surface area. The voltage required for each electrode spacing was measured over a five minute period and the spacing then changed. The data plotted on Figure 4 indicate that the potential required for the derusting process is a function of the electrode spacing and current required.

Throwing Power of a Single Anode on a Relatively Large Cathode Surface Area

In this experiment the cathode surface was 6 x 122 inches. The anode was located 6 inches away from the vertical centerline of the cathode 122 inch dimension. Cathode current density was maintained at 0.75 ampere per square foot of inner exposed area. Observations were made on potential required and on amount of cathode surface derusted.

The area closest to the anode was derusted first and then progressively, the more remote areas. The area over which complete derusting was accomplished is illustrated in Figue 5. It should be noted

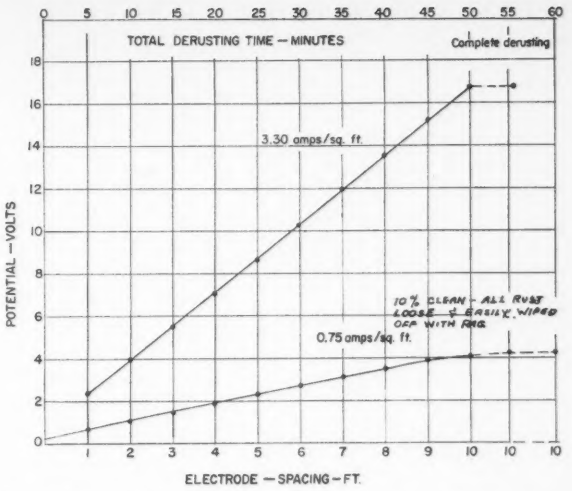
TOTAL DERUSTING TIME — MINUTES
Complete derusting
3.30 amps/sq. ft.
10% CLEAN - ALL RUST LOOSE & EASILY WIPED OFF WITH RAG
0.75 amps/sq. ft.
POTENTIAL — VOLTS
ELECTRODE — SPACING — FT.

Figure 4—Electrode spacing vs potential required for derusting steel plates. Cathode 5 x 6 x ⅛-inch rusted steel plate. Anode ¼-inch diameter steel welding rod opposite center of cathode. Electrolyte 3 percent sodium chloride solution at 74 F.

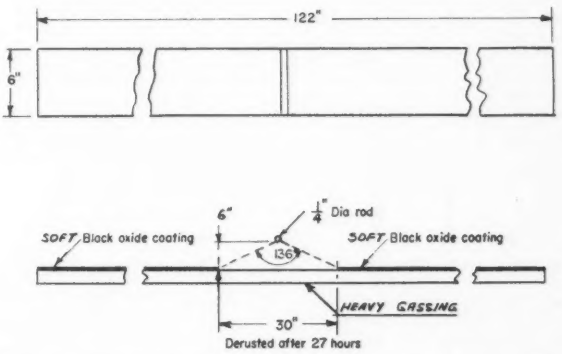

Figure 5—Throwing power of a single anode on relatively large cathode steel plate. Cathode 6 x 122 x ⅛-inch rusted steel plate. Anode ¼-inch sodium chloride solution at 71 F. Electrode spacing 6 inches. Cathode current 3.43 amperes.

that rust was removed entirely on the center 30 inches of the total 122 inches and was partially reduced to a soft black oxide on the remainder of the plate. Although the derusted area is limited, the throwing power of the anode is sufficiently good to make it only necessary to avoid excessively close electrode spacing in the design of an electrode system, since the area that may be derusted by using a single rod anode can be enlarged by increasing the distance between electrodes.

The correct spacing between the anode and cathode will depend to some extent upon the size and nature of the derusting operation and on the voltage of the available power supply. The voltage required for derusting is increased as the electrode spacing is increased, because of the added resistance in the current path. In order to utilize the throwing power of the anode and to keep the number of anodes to a minimum, the anode should be at least five feet from the closest part of the cathode, provided space permits. The cost of rigging anodes is an appreciable item in a large installation, but it is important

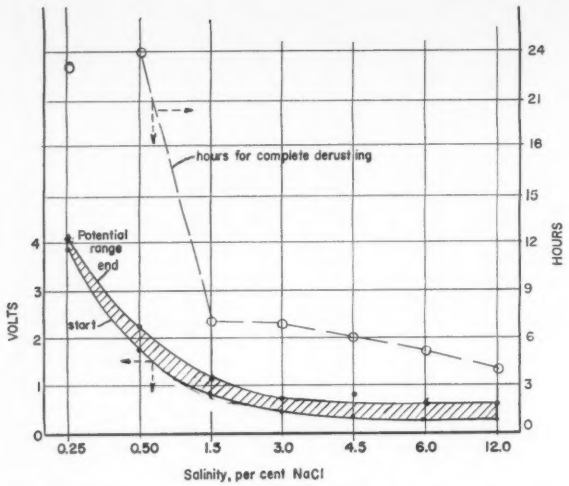

Figure 6—Electrolyte salinity vs time required for derusting steel plates. Cathode 5 x 6 x ⅛-inch rusted steel plate. Anode ¼-inch diameter steel welding rod or 1 x 6 x ⅛-inch steel strip. Electrolyte 3% sodium chloride solution at 70 to 74 F. Electrode spacing 14 inches. Cathode current density 0.50 ampere per square foot.

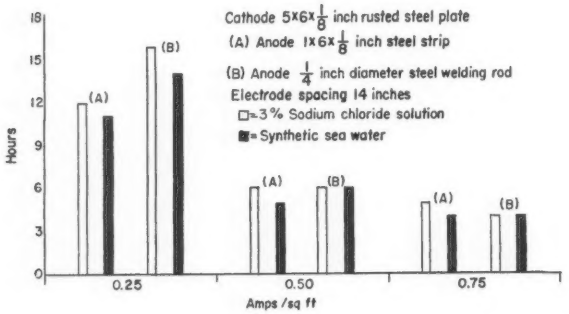

Figure 7—Comparison of 3 percent sodium chloride solution and synthetic sea water with time required for complete derusting.

that the anodes be located so as to assure a satisfactory distribution of current on the cathode. Anode location is an important factor in derusting a large space, such as a tanker compartment wherein the anode throwing power may be affected by pipes, stiffeners, or other structural members.

Removal of Mill-Scale by the Electrolytic Method

Several experiments were made to determine the efficacy of this method in the removal of tight mill scale. The specimens were coated with the original mill scale and had only small rusted areas. Various electrode spacing and cathode current densities were used. The observations were made on the applied potential and the condition of the cathodes. The data from these experiments are presented in Table 1. It should be noted that this method, using sodium chloride as the electrolyte, was not effective in removing tight mill scale, even though the ampere hours of current applied was considerably in excess of that normally required to remove rust.

Since thin tenaceous mill scale is composed mainly of ferrous oxide (FeO) next to the metal chemical

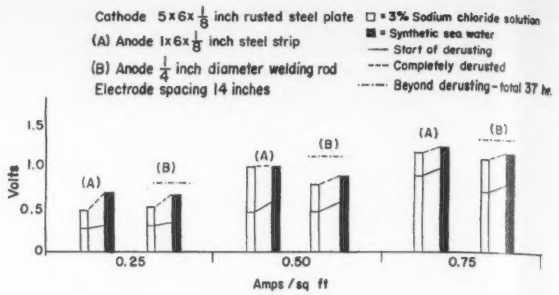
Cathode 5x6x⅛ inch rusted steel plate
(A) Anode 1x6x⅛ inch steel strip
(B) Anode ¼ inch diameter welding rod
Electrode spacing 14 inches
□ = 3% Sodium chloride solution
■ = Synthetic sea water
— Start of derusting
--- Completely derusted
-·- Beyond derusting - total 37 hr.
Volts
Amps / sq ft
0.25
0.50
0.75

Figure 8—Comparison of 3 percent sodium chloride solution and synthetic sea water with potential required at three current densities.

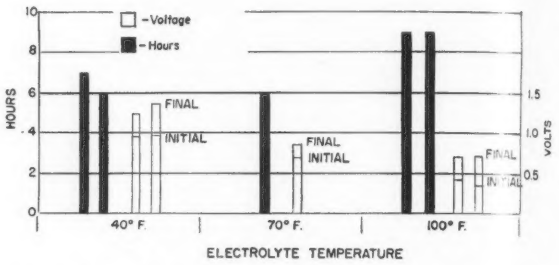

Figure 9—Electrolyte temperature vs derusting time of steel plates. Cathode 5 x 6 x ⅛-inch rusted steel plate. Anode 1 x 6 x ⅛-inch steel strip. Electrolyte 3 percent sodium chloride solution. Electrode spacing 14 inches. Cathode current density 0.50 ampere per square foot.

TABLE 2—Effect of Electrolytic Derusting On Adjacent Painted Surfaces

Cathode 7 x 11 x ⅛-inch steel plate half rusted and other half painted. Anode 1 x 6 x ⅛-inch steel strip. Electrolyte 3 percent sodium chloride solution at 72 F. Electrode spacing 6 inches. Auxiliary painted plate immersed in electrolyte but not electrically connected.

Cathode Current Density Amp./ Sq. Ft.	Derusting Time Hours	Potential Between Electrodes Volts	Rusted Cathode Percent Clean*	Condition of Plates	
				Painted Cathode	Aux. Painted Plate
0.25	0	0.49			
	3	.57	Rust Loose		
	6	.67	50	Loose at edges	
	10	.67	75	Blistered	
	14	.67	100	Paint off	No effect
0.50	0	0.90			
	2	97	Rust Loose		
	6	.96	80	Loose at edges	
	9		100	Blistered	
	14		100	Paint off	No effect
0.75	0	1.25			
	2	1.27	50		
	6	1.18	100	Loose at edges	
	10	1.19		Blistered	
	14	1.19		Paint off	No effect
1.00	0	1.54			
	2	1.43	60	Loose at edges	
	5	1.36	100	Blistered	
	10			Falling off	
	14			Paint off	

* After brushing with wet waste.

reduction by hydrogen to pure metal apparently cannot occur at ambient temperatures. Further, the presence of a strong alkaline environment near the steel cathode would tend to maintain the oxide of iron on its surface.

The second phase of this investigation consisted of using cathode specimens which were uniformly rusted prior to the start of the experiments. The anodes and/or the electrolytes were modified as indicated for each case.

Effect of Electrolyte Salinity on Time and Efficacy of Rust Removal

A series of experiments were run under identical conditions except that the salinity of the sodium chloride electrolyte was varied from 0.25 to 12 percent. Observations were made on potentials and condition of cathodes. The experiments were stopped shortly after derusting had been completed.

The data plotted in Figure 6 indicate that the time required for derusting is excessive with an electrolyte of low salinity, other factors being equal. Reasonably rapid derusting may be accomplished when the salinity is 1.5 to 3.0 percent. Higher salinities further reduce the time required for derusting but not in proportion to increase in salinity. It should also be noted that when the electrolyte salinity is low the potential required may be excessive. A practical salinity appears to be between 1.5 to 3.0 percent, however, 1.0 percent may be also suitable depending on the economics of the situation.

Comparison of Derusting with Electrolytes Consisting of 3% Sodium Chloride Solution and Synthetic Sea Water at Different Current Densities

Similar experiments were run with each of the two electrolytes and observations made on the voltage required and the condition of the cathodes. The experiments were discontinued shortly after derusting had been completed on one run, and were continued until fairly heavy residual deposits had accumulated on the cathodes in the other series.

It was shown that there was little difference between the two electrolytes in the time required for derusting. The residual deposit left on the cathode is different for the two electrolytes, being white for sea water and black for the sodium chloride solution. A spectroscopic analysis of the white residual coating showed principally magnesium with small amounts of iron, calcium, silicon, aluminum, boron and phosphorous in order of importance. An X-ray analysis of the coating revealed 80 to 90 percent of magnesium hydroxide. A similar X-ray analysis of the black residual deposit showed Fe_3O_4 (magnetite), only.

The similarity between derusting times and the potentials recorded are illustrated in Figures 7 and 8, respectively. In Figure 8, lines are used to connect comparison points on the bars.

Effect of Electrolyte Temperature on Time and Efficacy of Rust Removal

In this series of tests observations were made as to voltage required and on the conditions of the rusted cathodes until derusting was complete.

The data indicate that the process is effective in removing rust from steel plates when the temperature of the electrolyte is 40, 70 or 100 F. Within these temperature limits, no saving of time is indicated by the use of 100 F electrolyte and it is concluded that electrolyte temperature within these limits is not an important factor in the derusting process. Figure 9 illustrates the differences in derusting time and voltage obtained at the three temperatures. Duplicate runs were made at 40 and 100 F.

Effect of Electrolytic Derusting on Adjacent Painted Surfaces

In this series of experiments the cathodes consisted of 7 x 11 x ⅛" rusted steel plates, half the area of which was sandblasted clean and painted. The painting consisted of 1 coat of zinc chromate primer followed 24 hours later by 1 coat of an oleoresinous white paint which also was allowed to dry 24 hours. The anodes were 1 x 6 x ⅛ inch steel strips. The electrode spacing was 6 inches and the electrolye was a 3 percent sodium chloride solution at a temperature of 72 F.

The cathodes were derusted using current densities of 0.25, 0.50, 0.75 and 1.00 amp/sq. ft. An auxiliary plate painted as described for the cathodes was suspended in the electrolyte but was not included in the electrical circuit. Observations were made as to derusting time, potential between electrodes and the condition of the paint on both the connected and unconnected plates. Derusting occurred in a manner similar to that of previous tests, removal being accomplished after 14 hours at 0.25 amp/sq. ft. and after 5 hours at 1.0 amp/sq. ft. The paint on the other half of the cathode was deteriorated by the process. The paint was removed completely after 14 hours' exposure at all of the current densities tried, there being little or no variation in the rate of removal due to the difference in the current densities. The paint on the auxiliary plate was not affected visibly by immersion in salt water during the test. The data for these tests are contained in Table 2.

The third phase of the investigation dealt with additional factors involved in the electrolytic derusting process and with identification and removal of residual coatings deposited on cathodes when the process was continued beyond the time required for removal of rust. These experiments are described in the following paragraphs.

TABLE 3—Effect of Electrolytic Cleaning On Faying Surfaces
Cathode 5 x 6 x ⅛ inch steel plate with 2½ x 6 inch faying surface. Anode 1 x 6 x ⅛ inch steel strip. Electrolyte 3 percent sodium chloride solution at 70 F. Electrode spacing 14 inches.

Faying Surface	Cathode Current Density Amp./ Sq. Ft.	Derusting Time Hours	Potential Between Electrodes Volts	Remarks on Cathode	
				Exposed Area	Faying Area
Rust-rust	0.25	0	0.46		
		8	.48	50% clean*	
		16	.60	80% clean*	
		24	.66	100% clean*	Still rusted[1]
Rust-rust	0.50	0	0.67		
		8	.75	60% clean*	
		16	.87	85% clean*	
		20	.92	100% clean*	Still rusted[2]
		24	1.09	100% clean*	
Rust-rust	0.75	0	0.99		
		5	1.12	50% clean*	
		8	1.20	80% clean*	
		13	1.27	100% clean*	
		16	1.27	100% clean*	Still rusted[3]
Rust-rust	1.00	0	1.09		
		4	1.21	50% clean*	
		8	1.31	85% clean*	
		10	1.33	100% clean*	
		16	1.36	100% clean*	Still rusted[4]

* After wiping with wet waste.
[1] 50% of rust in original condition, others soft and black.
[2] 60% of rust in original condition, others soft and black.
[3] 90% of rust in original condition, others soft and black.
[4] 95% of rust in original condition, others soft and black.

TABLE 4—Effect of Electrolytic Cleaning on Faying Surfaces

Cathode 5 x 6 x ⅛ inch steel plate with 2½ x 6 inch faying surface. Anode 1 x 6 x ⅛ inch steel strip. Electrolyte 3 per cent sodium chloride solution at 70 F. Electrode spacing 14 inches.

Faying Surface	Cathode Current Density Amp./ Sq. Ft.	De-rusting Time Hours	Potential Between Electrodes Volts	Remarks on Cathode	
				Exposed Area	Faying Area
Clean steel-paint	0.50	0 7 12 15	0.93 .93 .93 .95	50% clean* 90% clean* 100% clean*	Steel rusty, paint good
Rust-paint	0.50	0 7 12 14	0.89 .83 .78 .85	50% clean* 90% clean* 100% clean	Unaffected
Paint-paint	0.50	0 7 12 14	0.93 .93 .89 .95	50% clean* 90% clean* 100% clean*	Unaffected
Clean steel-clean steel	0.50	0 7 12 14	0.80 .91 .89 .93	50% clean* 90% clean* 100% clean*	Rusty

* After wiping with wet waste.

TABLE 5—Effect On Dissimilar Metal and Faying Surfaces

Cathode 5 x 6 x ⅛ inch steel plate, 4 x 5 inch area rusted and 1 x 5 inch area clean and attached to dissimilar metal. Anode 1 x 5 x ⅛-inch steel strip. Electrolyte 3 per cent sodium chloride solution at 69 F. Electrode spacing 14 inches. Cathode current density 0.50 ampere per square foot. Auxiliary strip of dissimilar metal immersed in electrolyte but not electrically connected to electrodes.

Dissimilar Metal	De-rusting Time Hours	Potential Between Electrodes Volts	Remarks on Cathode		Auxiliary Dissimilar Metal Plate
			Rusted Plate % Clean*	Dissimilar Metal	
Brass	0 7 13	0.61 1.01 .99	50 100	Discolored	Clean
Aluminum	0 7 13	0.74 .91 .93	50 100	Corroded, slightly pitted	Discolored
Zinc	0 7 13	0.86 .97 .97	50 100	White film, no pitting	White film
Lead	0 7 14	0.59 .85 .97	50 100	Slight white film	Slight white film

* After wiping with wet waste.
Faying surfaces were not pitted.

TABLE 6—Residual Deposit On Steel Plate After Excessive Electrolysis in Synthetic Sea Water Electrolyte At 69 F

Cathode 5 x 6 x ⅛ inch rusted steel plate. Anode 1 x 6 x ⅛ inch steel strip. Electrode spacing 14 inches.

Cathode Current Density Amp./Sq. Ft.	Derusting Time Hours	Potential Between Electrodes Volts	Remarks on Cathode
1.00	0	1.25	
	2	1.61	Rust loose
	3	1.60	100% clean
	4	1.59	Slight white residual coating
	7	1.50	Heavier white residual coating
	24	1.56	Heavier white residual coating
	32	1.52	Heavier white residual coating

Spectrographic analysis of the white residual coating showed principally magnesium, with small amounts of iron, calcium, silicon, aluminum, boron and phosphorous in order of importance.

X-ray analysis of the white residual coating showed 80 to 90 percent of magnesium hydroxide.

Electrolytic Cleaning of Faying Surfaces

Experiments were run to determine whether faying surfaces could be cleaned. The conditions were as follows:

1) Electrolyte—3 percent sodium chloride solution.
2) Anode—steel strip 1 x 6 x ⅛ inch.
3) Electrode spacing—14 inches.
4) Electrolyte temperature—70 degrees F.
5) Cathode current density—0.25 to 1.00 ampere per square foot of exposed inner surface area.
6) Each cathode was composed of one plate 5 x 6 x ⅛ inch with one-half its surface, facing the anode, covered by a 2½ x 6 x ⅛ inch steel plate secured with six ¼ inch diameter steel bolts and nuts. The exposed surfaces of both cathode parts were rusted as previously described for all cathodes. The various faying surfaces were as follows:
   a) Rusted steel against rusted steel.
   b) Clean steel against clean steel.
   c) Painted steel against painted steel.
   d) Rusted steel against painted steel.
   e) Clean steel against painted steel. The clean steel was prepared by cleaning with a wire brush and emery paper. The painted faying surfaces were cleaned and painted as described previously.
7) The electrolysis was continued until the exposed rusted parts of the cathode were free from rust and in some instances longer. During the process recordings of voltage and cathode condition were made. Promptly upon completion of electrolysis the faying surfaces were disassembled and examined.

The data of Tables 3 and 4 indicate that the electrolytic process is not effective in cleaning faying surfaces, even when continued beyond the point where the exposed cathode surfaces are clean. Further, rusting will likely occur on steel faying surfaces which were clean at the start of the process.

Effect of Electrolytic Cleaning on Dissimilar Metals Attached to Rusted Steel Plates

During these experiments various non-ferrous metals were attached to rusted steel cathodes. The following conditions prevailed:

1) Electrolyte—3% solution of sodium chloride at temperature of 69 F.
2) Anode—steel strip 1 x 6 x ⅛ inch.
3) Electrode spacing—14 inches.
4) Cathode current density—0.50 ampere per square foot of inner surface area.
5) Cathodes—rusted steel plates 5 x 6 x ⅛ inch, each with a cleaned area 1 x 5 inch to which a clean dissimilar metal strip 1 x 5 x ¼ inch was attached by six ⅛ inch steel bolts with steel nuts. This produced a faying surface between the steel plate and the dissimilar metal. The dissimilar metals were:
   a) Aluminum, Alcoa 2S, 99.1 percent pure.
   b) Zinc, 99.9 percent pure.
   c) Lead, 99.9 percent pure.
   d) Brass, 70 percent copper and 30 percent zinc.
6) During each experiment, a duplicate of the cathode was immersed in the electrolyte, but was not connected to either electrode.
7) The experiments were run until the cathodes had been completely derusted. Then the dissimilar metals were unbolted and all parts thoroughly examined.

The data as presented in Table 5 indicate that the brass, zinc and lead were not appreciably damaged by electrolyte cleaning as determined visually. Pitting occurred on the exposed surface of the aluminum, but not on the faying surface. The fact that attack occurred on aluminum, combined with other data presented later regarding the nature of the residual deposits on the cathodes, suggests that the

damage was caused by alkalinity generated at the cathode. Thus, any application of cathodic cleaning methods should carefully consider the nature of the metals to be cleaned as well as that of the electrolyte.

Residual Deposits on Steel Cathodes During Electrolytic Derusting

A series of experiments was run to investigate the formation of residual deposits on steel cathodes during electrolytic derusting. In these experiments, normally rusted steel cathodes were used, the anodes were steel strips, and various cathode current densities and electrolytes were used, the details of which can be found in Tables 6 and 7. The electrolysis period was extended beyond the time required for complete derusting of the cathodes.

The residual deposits left on steel cathodes found during experiments described above were identified by spectrographic, X-ray and/or chemical analysis. Also, the residual material left on steel compartment walls of a vessel undergoing cleaning at New York Naval Shipyard was analyzed. The results are included in Tables 6 and 7. When the electrolyte is synthetic sea water the residual deposits are white, and when the electrolyte is a sodium chloride solution the deposits are black. The white deposit from the synthetic sea water formed at a current density of 1.0 amp/sq. ft. was 80 to 90 percent magnesium hydroxide with small amounts of iron, calcium, silicon, aluminum, boron and phosphorous. The black deposit resulting from the 3 percent sodium chloride solution at a current density of 0.25 amp/sq. ft. had a composition of 100 percent Fe_3O_4 (magnetite). The black deposit from the floating drydock using a 1 percent sodium chloride solution and a current density of 0.10 amp/sq. ft. was composed of 65 percent Fe_3O_4 and 35 percent FeO·OH.

Effect of Current Reversal on Residual Deposits Left on Steel Cathodes

The residual deposits were formed on steel plates by using synthetic sea water as the electrolyte and continuing the electrolytic derusting process longer than necessary to remove the rust. The current was then reversed so that the anode became the cathode and vice versa. The results of Table 8 indicate that the long time reversal of the current did not appreciably remove the white deposit.

Effect of Addition of Sulfuric Acid to Electrolyte Before Starting Derusting Process

In this series of experiments various percentages of sulfuric acid were added to the electrolyte prior to starting the derusting process. The experiments ran concurrently. Periodic observations were made on voltage and condition of cathodes. The passage of current was continued until the residual coating had been formed or had failed to form during a 48 hour period after rust removal. The electrolyte pH was measured at the start and the end of the period.

Figure 10 illustrates some of the data recorded. It should be noted that the pH of the synthetic sea water became less and less in a fairly constant manner with each addition of H_2SO_4. In Figure 10 this is illustrated by the curve labeled "pH of electrolyte at start of derusting." The corresponding curve for the "pH of electrolyte after derusting" indicates that this pH remains practically unchanged for additions of acid up to 0.34 percent. Between this concentration and 0.86 percent the pH becomes much lower and approaches that of the electrolyte before derusting throughout the remainder of concentrations. None of the white deposit was formed on the cathodes for acid concentrations of 0.86 percent and greater which cor-

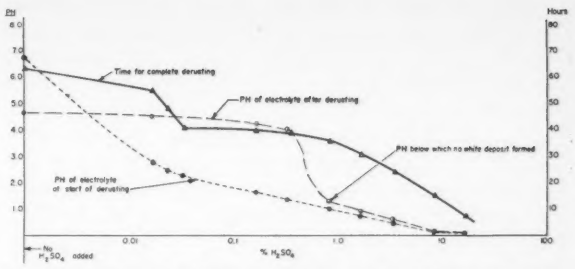

Figure 10—Effect of addition of sulfuric acid to synthetic sea water electrolyte on initial and final pH and time for complete derusting. Cathode 1x4x¼-inch steel strips. Anode ⅛-inch diameter steel welding rod. Electrolyte synthetic sea water at 69 to 71 F. Electrode spacing 3 inches. Cathode current density 0.25 ampere per square foot.

TABLE 7—Residual Deposit On Steel Plate After Excessive Electrolysis in 3 Percent Sodium Chloride Solution At 71 F

Cathode 5 x 6 x ⅛ inch rusted steel plate. Anode 1 x 6 x ⅛ inch steel strip. Electrode spacing 14 inches.

Cathode Current Density Amp./Sq. Ft.	Derusting Time Hours	Potential Between Electrodes Volts	Remarks on Cathode
0.25	0	0.23	
	6	.39	Rust becoming loose
	22	.66	Slight residual black deposit scraped off for analysis

X-ray diffraction analysis of the black residual deposit showed Fe_3O_4, only.

X-ray diffraction analysis of a black residual deposit taken from the steel walls of tank compartments of the vessel ARD-7 after 168 hours at electrolysis in 1 percent solution chloride solution with platinum anodes at cathode current density of 0.10 ampere per square foot, showed as follows: 65 percent Fe_3O_4, 35 percent FeO.OH.

TABLE 8

Cathode 5 x 6 x ⅛ inch rusted steel plate. Anode 1 x 6 x ⅛ inch steel strip. Electrolyte synthetic sea water at 73 F. Electrode spacing 14 inches.

Cathode Current Density Amp./Sq. In.	De-rusting Time Hours	Voltage Between Electrodes Volts	Remarks on Cathode	Remarks on Anode
1.00	0	1.05		
	4	1.37	100% clean	
	5	1.38	Slight white deposit	
	8	1.33	Heavier white deposit	
Current Reversed	24	1.39	Heavier white deposit	
	24	1.39		
	32	1.51		Unaffected
	96	1.67		Unaffected
	120	1.65		Unaffected
1.00	0	1.22		
	4	1.52	100% clean	
	5	1.51	Slight white deposit	
	8	1.49	Heavier white deposit	
Current Reversed	24	1.43	Heavier white deposit	
	24	1.39		
	32	1.67		Unaffected
	96	1.83		Unaffected
	120	1.77		Unaffected

NOTE: The cathodes became anodic when the current was reversed but the white residual deposit was unaffected.

responds to a pH of approximately 1. It was always formed however at concentrations of 0.34 percent and less. The other curve "time for complete derusting" indicates that the first additions of acid, even though minor in amount, causes an appreciable drop in the time required for complete derusting. Further additions of acid up to 0.86 percent causes only a slight decrease in time. Above that concentration the time required again decreases appreciably with each increase in acid content.

It was noted that when sulfuric acid was used in the electrolyte the resulting bare surfaces were left in a highly active condition and were thus subject to rapid rerusting, especially if the acid was not thoroughly removed.

Effect of Adding Sulfuric Acid to the Electrolyte After Formation of Residual White Deposit on Steel

In this series of experiments the acid was added after the steel had been derusted and a heavy white deposit formed. The results are plotted in Figure 11. Apparently slightly less acid is required to remove the residual white deposit if the acid is added after the derusting is complete and the electrolytic process continued than if the acid is added at the start of the cleaning process. The white deposit may be removed by adding a relatively small amount of sulfuric acid but in this case the time required is about 24 hours. When the amount of sulfuric acid added is 0.86 percent or more by weight, the time required for cleaning the steel of the white deposit is four hours or less. To permit rapid removal of the white deposit, electrolyte pH must be reduced to the order of 1 or lower.

Further work on the effect of acid additions on the efficiency of descaling has been accomplished by the U. S. Civil Engineering Research Laboratory, Port Hueneme, California.[24]

Effect of Electrolytic Derusting on Hydrogen Embrittlement of Steel

Two series of tests were run. In the first, the cathodes were tensile strength specimens 3.25 inches in length and 0.357 inch in diameter prepared from medium carbon steel. These clean cathodes were electrolyzed in synthetic sea water at 70 F for 48 hours using a current density of 1.00 amp/sq. ft. of exposed surface area. The anodes were steel strips 1 x 6 x ⅛ inch located 14 inches from the cathodes. At the end of the electrolysis period, the cathode specimens were tested for tensile strength and elongation and the results compared with those from similar specimens unelectrolyzed. The results are tabulated and averaged in Table 9. It will be noted that there was no appreciable difference between electrolyzed and unelectrolyzed specimens. It is recognized that the data presented in the subject test are open to criticism as the method used did not adequately test for loss in ductility.

In the second series of tests the cathodes were prepared from two pieces of medium-carbon structural steel, each 12 x 4 x ½ inch. These pieces were butt-welded and then cut into flexural test specimens each 1 x 8 x ½ inch with the welded section at the center of the 8 inch dimension. These clean specimens were electrolyzed in synthetic sea water at 68 F for 72 hours at a current density of 0.50 amp. per sq. ft. of exposed surface area. The anodes were steel strips 6 x 1 x ⅛ inch spaced 14 inches from the cathodes. At the end of the electrolysis period, the electrolyzed specimens and similar specimens unelectrolyzed were subjected to a transverse bend test, with the load applied at the welded part, through an angle of 180 degrees. The results are tabulated and averaged in Table 10. It will be noted that the average flexural

TABLE 9—Effect of Electrolytic Descaling on Hydrogen Embrittlement of Steel

Tensile strength specimens 3.25 x 0.357-inch in diameter

Specimen Number	Electrolyzed	Yield Point Pounds	Breaking Point Pounds	Tensile Strength Lbs./ Sq. In.	Percent Elongation in 1.4 Inch Gage Length
1	No	4600	6500	65,000	36.5
2	No	4800	6700	67,000	36.5
3	No	4600	6700	67,000	37.3
Average 1-3	No	4666	6633	66,330	36.8
4	Yes	4825	6675	66,750	37.1
5	Yes	4750	6600	66,000	37.1
6	Yes	4850	6700	67,000	37.1
Average 4-6	Yes	4808	6658	66,580	37.1

TABLE 10—Effect of Electrolytic Descaling on Hydrogen Embrittlement of Steel

Flexural strength, welded steel specimens

Specimen Number	Electrolyzed	Maximum Load Pounds	Deflection Angle Degrees	Specimen Failure
1	No	8000	180	None
2	No	8300	180	None
3	No	8850	180	None
4	No	8800	180	None
5	No	8000	180	None
6	No	9300	180	None
Average 1 to 6		8542		None
7	Yes	7800	180	None
8	Yes	8100	180	None
9	Yes	8100	180	None
10	Yes	7600	180	None
11	Yes	7900	180	None
12	Yes	7900	180	None
Average 7-12		7900		None

TABLE 11—Effect of Adding Addition Agents To Electrolyte Before Electrolytic Descaling

Cathode 5 x 6 x ⅛-inch rusted steel plate. Anode 1 x 6 x ⅛-inch steel strip. Electrolyte synthetic sea water at 68 F. Electrode spacing 14 inches. Cathode current density 0.25 ampere per square foot.

Addition Agent	De-rusting Time Hours	Voltage Between Electrodes Volts	Electrolyte pH	Condition of Cathode
None	0	0.41	6.37	Rusty
	18	.70	5.51	90% free of rust
	19	.71		100% free of rust
	42	.77		Heavy white deposit
	48	.75	5.00	Heavier white deposit
Antarox A-180...	0	0.27	6.60	Rusty
0.04% by volume	18	.68	5.62	100% free of rust
	26	.75		Slight white deposit
	42	.78		Heavy white deposit
	48	.78	4.68	Heavier white deposit
Antarene X-235..	0	0.37	8.22	Rusty
0.2% by weight..	18	.72	7.66	80% free of rust
	22	.71		100% free of rust
	26	.71		Slight white deposit
	42	.75		Heavy white deposit
	48	.75	6.62	Heavier white deposit
Antaron L-135...	0	0.30	6.87	Rusty
0.1% by weight..	3	.41		Rusty
	19	.81	5.97	100% free of rust
	27	.87		Slight white deposit
	43	.90		Heavy white deposit
	49	.85	5.94	Heavier white deposit

TABLE 12—Effect of Adding Addition Agents To Electrolyte Before Electrolytic Descaling

Cathode 5 x 6 x ⅛-inch rusted steel Plate. Anode 1 x 6 x ⅛-inch steel strip. Electrolyte 3 percent sodium chloride solution at 69 to 71 F. Electrode spacing 14 inches. Cathode current density 0.25 ampere per square foot.

Addition Agent	De-rusting Time Hours	Voltage Between Electrodes Volts	Elec-trolyte pH	Condition of Cathode
None.....	0	0.23	6.33	Rusty
	6	.39		Rusty
	22	.66	5.97	Free of rust, slight black deposit
Antarox A-180 0.04% by volume.	0	0.15	6.72	Rusty
	5	.48		Rusty
	21	.62	6.33	60% free of rust
	23	.61		100% free of rust
	29	.74		Slight black deposit
	47	.78	5.99	Heavier black deposit
Antarene X-235 0.2% by weight..	0	0.31	9.35	Rusty
	5	.45		Rusty
	21	.70	9.84	90% free of rust
	23	.73		100% free of rust
	29	.75		Slight black deposit
	47	.79	9.40	Heavier black deposit
Antaron L-135 0.1% by weight..	0	0.24	6.80	Rusty
	5	.45		Rusty
	21	.79	6.63	90% free of rust
	22	.79		100% free of rust
	29	.80		Slight black deposit
	47	.79	6.63	Heavier black deposit

strength for the electrolyzed specimens was 7900 pounds as compared to 8542 pounds for the unelectrolyzed, and that none of the specimens failed to withstand bending through an angle of 180 degrees. Inasmuch as the anticipated adverse effect of hydrogen is embrittlement, it is concluded that no such effect was produced on the steels in question. It is now believed that impact testing data or the exposure of the specimen under stresses would have been more conclusive.

The fourth phase of this investigation dealt with the effect of the addition of detergents, use of anodes other than steel, and the application of this electrolytic method to the cleaning of a scale coated brass condenser tube.

The Effect of Addition of Detergents on Efficacy of Electrolytic Cleaning

The following proprietary addition agents, in quantities as recommended by the manufacturer, were added to the 3 percent sodium chloride and synthetic sea water electrolytes at the start of the cleaning process.

a. Antrox A-180, an alkyl aryl polyethylene glycol, an oily viscous liquid.

b. Antarene X-235, the sodium salt of a tetracarbozylic diamine, a white powder.

c. Antaron L-135, the sodium salt of a fatty amide sulfonate, a white powder.

Periodic observations were made on voltage required, condition of cathode, time required for derusting and electrolyte pH reading. These data are recorded in Tables 11 and 12. The three addition agents, as used, were not effective in reducing the time required for derusting or in preventing the formation of residual deposits on the cathode when the cleaning period was extended beyond the time required for complete derusting.

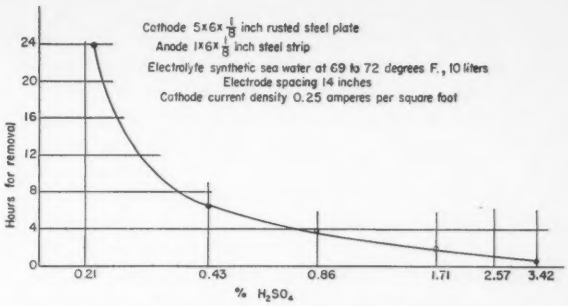

Figure 11—Effect of additions of sulfuric acid to the electrolyte after formation of residual deposit on the rate of removal.

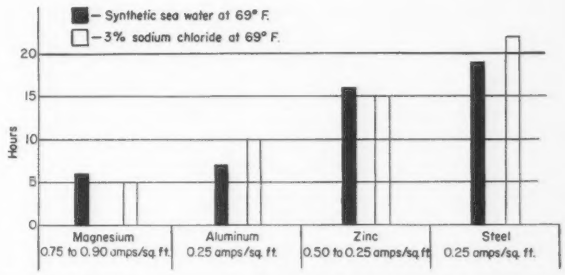

Figure 12—Effect of use of various anodes in derusting of steel on time of complete derusting. Cathode 5 x 6 x ⅛-inch rusted steel plate. Anode 1 x 6 x ¼-inch strip of metal. Electrode spacing 14 inches.

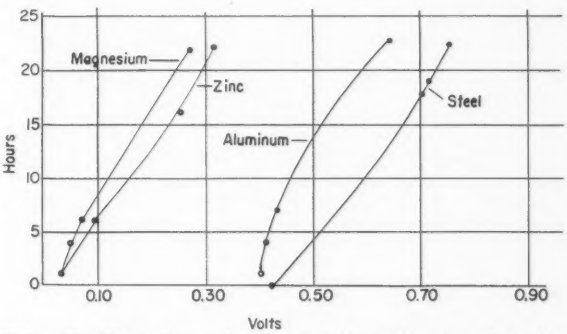

Figure 13—Effect of use of various anodes in derusting of steel on potential between electrodes. Electrolyte synthetic sea water at 69 F.

The Effect of the Use of Other Soluble Anodes in Lieu of Steel Anodes

In this series the cathodes were rusted steel, the anodes were strips of steel, magnesium 99.8 percent, aluminum Alcoa 2S, 99.1 percent and zinc 99.9 percent. Electrocleaning was continued until the steel cathodes had been derusted and then for an additional period to note the formation of residual deposits. Observations were made on the voltage required and on pH of electrolyte. The data indicate that soluble non-ferrous anodes such as magnesium, aluminum, and zinc may be used in lieu of steel during the derusting process. However, these metals are normally electronegative with respect to steel therefore the applied voltage would normally be high when maintaining the anode electropositive with respect to steel during the derusting process. The effect of the use of the various anodes is illustrated in Figure 12. For magnesium and initially for zinc, it was impossible to

attain a current density as low as 0.25 amp/sq. ft. when applying voltages for reversing the polarity of these metals with respect to steel. It should be noted for example, that the time required for complete derusting when using magnesium anodes, was approximately ¼ of that when using steel, but that the amperage for magnesium was 3 to 4 times more than for steel. The comparison between the use of aluminum and steel anodes, however, leads to the conclusion that it may be possible to decrease derusting time by the substitution of aluminum for steel without a proportionate increase in current consumption. Figure 13 illustrates the effect of the use of various soluble anodes on the potential as measured between the electrodes when using synthetic sea water as the electrolyte. Essentially the same type of data was obtained when using 3 percent sodium chloride. At zero impressed current the galvanic circuit potential was observed to be the same between steel and the various non-ferrous anodes in either the synthetic sea water electrolyte or the 3 percent sodium chloride solution. It is also interesting to note that the residual deposits on the cathodes when using synthetic sea water as the electrolyte were recorded as heavy for magnesium and steel anodes and as slight for aluminum and zinc anodes.

The Effect of the Use of an Insoluble Anode of Platinum in Lieu of a Steel Anode

In this series the cathodes were rusted steel plates and the anodes were sections of platinum wire. The experiments were continued until the cathode rust had disappeared and residual deposits had developed.

TABLE 13—Use of Insoluble Anode, Platinum During Derusting of Steel Plates

Cathode 1¾ x 6 x ⅛-inch rusted steel plate. Anode platinum wire, 0.015 inch diameter, 10-inch loop. Electrolyte temperature 68 F. Electrode spacing 7 inches. Cathode current density 0.10 ampere per square foot.

Electrolyte Addition Agent	Derusting Time Hours	Voltage Between Electrodes Volts	Electrolyte pH	Condition of Cathode
1% NaCl Solution	0	1.96	6.60	Rusty
	2	2.20		Rusty
	18	2.27		Rusty
	26	2.28		Rusty
	42	2.31	4.00	25% free of rust
	50	2.31		40% free of rust
	66	2.23		80% free of rust
	72	2.25		100% free of rust
	74	2.25	3.90	Slight black coating
Synthetic Sea Water	0	1.77	6.46	Rusty
	6	2.18		Rusty
	23	2.24	3.82	Rusty
	31	2.22		Rusty
	47	2.33		10% free of rust
	55	2.32		20% free of rust
	71	2.31		60% free of rust
	78	2.29		70% free of rust
	88	2.29		100% free of rust
	96	2.29	4.27	Slight white coating

NOTE: Platinum anodes gassed slightly throughout the experiments, but lost no weight. Slight odor of chlorine was noted.

TABLE 14—Analysis of Sample of Scale Removed from the Brass Evaporator Tube from the *USS Tanner*

	%		%
Moisture	1.61	MgO	3.61
Loss on ignition (chiefly CO_2)	30.73	SO_4	5.34
SiO_2	6.25	C	0.05
Fe_2O_3	10.53	Ni	Trace
CaO	41.42	Zn	Trace

The condition of cathodes, required voltage and pH of electrolytes are recorded in Table 13. It appears practical to use platinum wire under certain circumstances. The time required for complete derusting was greater than for other anodes tested due to the limited current carrying capacity of the wire used. Present day commercial techniques of cladding wire and metal bars with a thin impervious layer of platinum can reduce the initial high cost of a platinum installation and at the same time increase current carrying capacity of such a system so that it can compete economically with steel anodes. Light weight platinum-clad wires can be suspended conveniently with nylon or other suitable cords resulting in a saving in labor. It is interesting to note that the platinum exhibited no loss in weight during the derusting process and it did not prevent the formation of residual deposits on the cathode after the rust had been removed. A chlorine odor was detected when the platinum anode was used. Recent investigations of high silicon raw materials show promise as an inexpensive fairly insoluble anode.

The Application of the Electrolytic Cleaning Method to the Cleaning of a Scale Coated Brass Condenser Tube

The tubes for this experiment were removed from the first effect tube nest of the low pressure distilling unit of the USS *Tanner*. They consisted of two sections each 2½ feet long and ⅝-inch diameter, heavily coated on the outside with scale. In these experiments the cathode consisted of a 6-inch length of the tube with the lower 4 inches immersed in 3 percent sodium chloride electrolyte. The anode was a steel welding rod placed 3 inches from the cathode. After 8 hours' exposure at a current density of 0.75 amp/sq. ft. the scale was somewhat loosened and could be picked off, except on the side of the tube away from the anode. Heavy gassing occurred at points where the scale was broken. A second run for 14 hours using a current density of 0.25 amp/sq. ft., produced no effect on the scale except for slight removal where the scale was broken at the start. A repeat of the second run, but with all breaks in the scale and bare metal carefully coated with sealing wax, resulted in no current flow at all. Another repeat of the second run but with 1 percent hydrochloric acid by weight added to the electrolyte, resulted in the removal of 95 percent of the scale within 150 minutes with some hard spots remaining. In comparison, a similar specimen of the tube immersed in 1 percent by weight of hydrochloric acid was completely cleaned of scale in 120 minutes. When using 5 percent hydrochloric acid the cleaning time for a tube section was 30 minutes. From these results it is concluded that the electrolytic cleaning method will not be effective in removing scale deposits that are similar in nature to the residual coatings deposited from the electrolyte by the electric current itself. The composition of the scale as reported in Table 14 indicates that it is composed mainly of calcium compounds associated with iron, magnesium and silica.

The fifth phase of this investigation conducted at the Puget Sound Naval Shipyard related to the amount of gases given off at the cathode during the

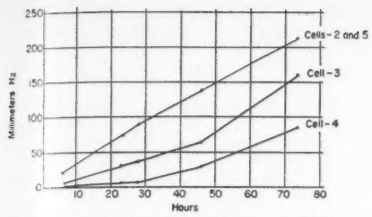

Figure 14—Volume of hydrogen evolved—Series A.

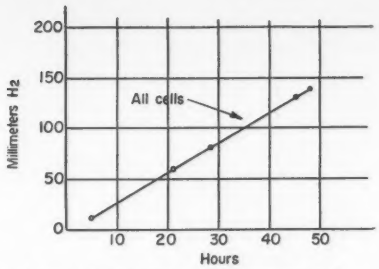

Figure 15—Volume of hydrogen evolved—Series B.

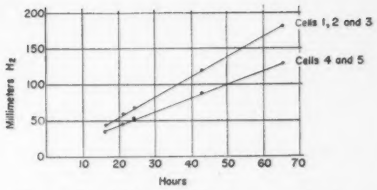

Figure 16—Volume of hydrogen evolved—Series C.

electrolyte cleaning process and the nature of the reaction.* In these experiments unles otherwise stated, the electrolyte was natural sea water. The current density was 0.5 amp/sq. ft. The electrodes were connected in series so that the electricity supplied was the same for each cell in each of the test series conducted, the cathodes were placed inside of an inverted graduated cylinder so that all gas given off was collected and measured. Insulating lacquer or paint was used to cover all bare portions not intended to be used as part of the cathode. The anodes were of sheet aluminum and the cathodes were made in various ways and of various metals as described later under test Series A to E, and H inclusive. The results are illustrated in Figures 14 to 19.

In Series A, the anodes and cathodes were as follows:

Cell No.	Anode	Cathode
2	Aluminum	Platinum
3	Aluminum	Clean steel in contact with a slab of scale
4	Clean steel	Rusty steel
5	Aluminum	Clean steel

It should be noted from Figure 14 that the hydrogen evolution was the same for cells 2 and 5 from which the hydrogen was evolved in theoretical amounts, and progressively lower for cells 3 and 4. Plate 1 shows the assembly of cell 3 of series A. The rust on the cathode of cell 4 was dark and red at first. This color changed to black with the rust sloughing toward the end of the run. The iron content of the electrolytes of this series was determined after the electrolysis and was as follows: Cell 2—0.1 ppm; Cell 3—1.5 ppm; Cell 5—0.4 ppm; Blank—0.1 ppm.

The electrolyte for cell 4 was not analyzed because an iron anode had been used and considerable iron introduced from this source. These data show that very little iron is dissolved from the cathode.

In series B, the cathodes were as follows:

Cell No.	Cathode
1	Platinum
2	Clean steel
3	Clean steel surrounded by ferric hydroxide held mechanically around the cathode by a cloth sack
4	Clean copper
5	Clean copper and ferric hydroxide as for Cell 3

*Adapted from Puget Sound Naval Shipyard "Electrolytic Descaling." Report 222C-3, November, 1949.

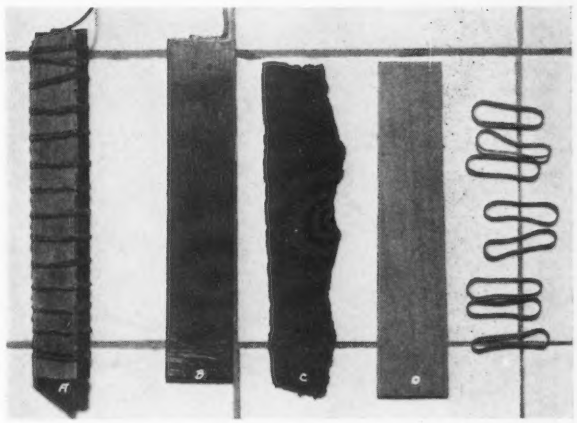

Plate 1*—a) assembled cathode, b) clean steel plate, c) piece of rust, d) porous wood for mechanical protection, e) rubber bands.

The amount of hydrogen evolved is shown in Figure 15. The volume of hydrogen produced was the same for all of the cells throughout the electrolysis. These data indicate that the ferric hydroxide did not react and that the copper cathode behaved in a manner similar to a steel cathode.

In series C, the cathodes were as follows:

Cell No.	Cathode
1	Platinum
2	Clean steel
3	Clean steel surrounded by ferrous hydroxide held mechanically around the cathode by a cloth sack.
4	Clean steel surrounded by powdered scale held as described for Cell 3.
5	Clean copper cathode surrounded by powdered scale held as described for Cell 3.

The amount of hydrogen evolved is shown in Figure 16. It should be noted that the volume of hydrogen produced was the same for Cells 1, 2 and 3. Cells 4 and 5 evolved a somewhat lower amount of hydrogen thus indicating that another reaction was occurring. After the test run was complete the apparatus was allowed to stand for 24 hours to determine if there was any mechanically held gas in cathodes 3, 4 and 5 that would come out. None was found. The scale used was magnetic but the ferrous hydroxide was not.

* All plates in this article are reproduced from Official U. S. Navy Photographs through courtesy of Bureau of Ships.

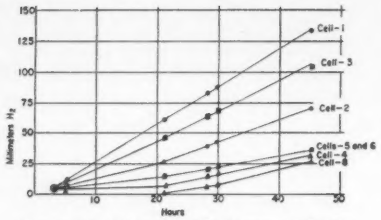

Figure 17—Volume of hydrogen evolved—Series D.

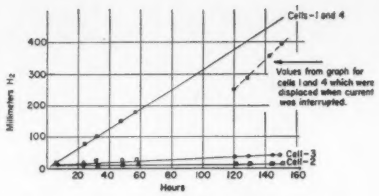

Figure 18—Volume of hydrogen evolved—Series E.

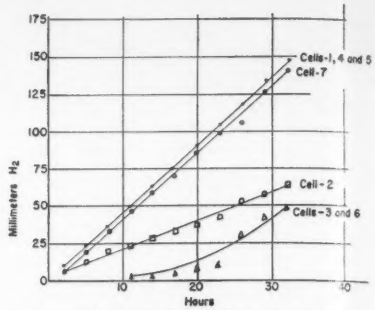

Figure 19—Volume of hydrogen evolved—Series H.

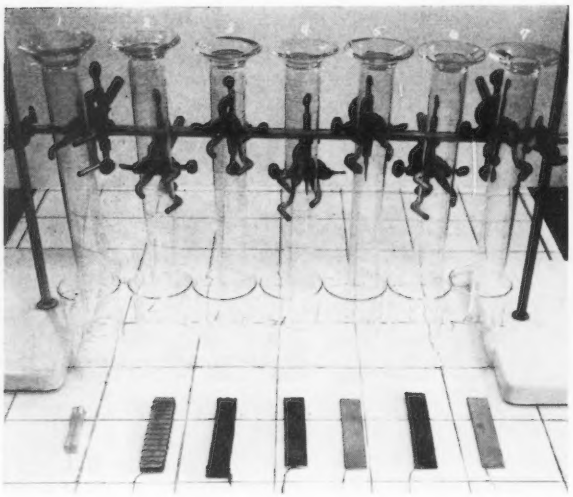

Plate 2—View of cells and controls—Series H.

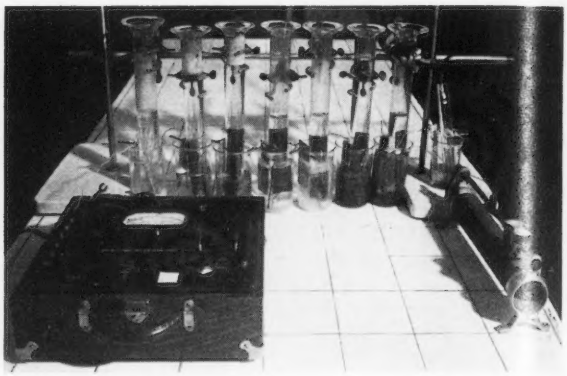

Plate 3—Cathode and glass collectors of Series H.

In series D, the cathodes were as follows:

Cell No.	Cathode
1	Platinum
2	Clean steel in contact with a slab of scale, with the surface of the scale normally away from the metal away from the cathode.
3	Similar to Cell 2 except that the slab scale was reversed so that the surface normally in contact with the metal was away from the cathode.
4	Similar to Cell 2 except that clean copper was used instead of steel.
5	Similar to Cells 2 and 4 except that Bendalloy (an easily fusible alloy of tin, bismuth, cadmium, and lead) was cast onto the scale. The surface of the scale next to the Bendalloy was the side normally next to the metal.
6	Similar to Cell 5 except that the surface of the scale normally in contact with metal was turned away from the cathode as in Cell 3.
8	Rusty Steel

The amount of hydrogen evolved from each is illustrated in Figure 17. It was noted that scale and rust in contact with the metal reduced the amount of hydrogen evolved and the closer the contact between the scale or rust to the metal the less hydrogen produced. The differences between Cell 1 and the remaining cells appear to be due to difference in closeness of contact between the metal and the scale or rust. Cell 7 of this series had a Bendalloy cathode, but difficulty was experienced which made the results unreliable.

Series E repeated Series D for this Bendalloy cathode. In Series E the cathodes were as follows:

Cell No.	Cathode
1	Platinum
2	Cast Bendalloy cast onto scale with the surface of the scale normally in contact with the metal turned toward the Bendalloy.
3	Similar to Cell 2 except that the surface of the scale normally in contact with the metal was turned away from the Bendalloy.
4	Bendalloy

Due to the electric circuit being interrupted during part of the run, the time interval versus hydrogen volume relationship is not the same as for Series D. However, time is the same for all of the cells. Figure 18 illustrates the results obtained. The upper portion of the graph for Cells 1 and 4 is an extrapolation of the lower portion since the upper portion was displaced due to the current interruption. This extrapolation is based on the fact that this graph represents the theoretical amount of hydrogen that is possible to be evolved. The curves for Cells 2 and 3 lead to the conclusion that the reaction which does not produce hydrogen is more complete when the side of the scale normally in contact with the metal is next to the cathode. This difference could be due to differences in the degree of contact between the two faces of the slab of scale and the cast Bendalloy as previously suggested or it could be due to composition differences between the two faces of the slab of scale.

In Series H the anodes and cathodes were as follows:

Cell No.	Anode	Cathode
1	Aluminum	Platinum
2	Aluminum	Same as Cell 2 of Series D
3	Aluminum	Rusty steel
4	Aluminum	Steel coated with mill scale
5	Aluminum	Clean steel
6	Steel	Rusty steel
7	Steel	Clean steel

The results are illustrated in Figure 19. It will be noted that the hydrogen evolved was essentially the same in volume from Cells 1, 4, 5 and 7. Also steel substituted for aluminum in the anode made practically no difference in the volume of hydrogen evolved. The results obtained with Cell 4 for which the cathode was steel coated with mill scale were consistent with results reported in the preceding paragraph in which electrolytic cleaning failed to remove a mill scale coating. No removal would be expected since apparently no reaction other than evolution of hydrogen is taking place as it appears to be for Cells 2, 3 and 6. Plates 2 and 3 show apparatus used in Series H.

Discussion of Derusting Theory

Careful observations of numerous electrolytic experiments using 3 percent sodium chloride as an electrolyte revealed that the first outward indication of cleaning is that of the lifting of an outer layer of red rust presumably by the action of the hydrogen. The higher the current density, the faster is the removal of the red rust layer. The loosened red rust is observed to fall off in flakes which do not appear to have been acted upon chemically. A black residual layer remains after this red rust has been removed. It is not easily detached by further gasing. Instead the cathodic reaction seems to have a gradual softening effect which makes the later removal of this black coating comparatively easy by brushing or wiping. It was also observed that a few drops of phenolpthalein indicator turn pink in the vicinity of the cathode showing the presence of $(OH)^-$ ions.

While the purpose of this investigation was not to determine the theory of cathodic derusting, it is considered pertinent to present several of the theories that have been advanced and to comment briefly on the purport of this data. These theories are:

1. Probably the oldest theory advanced to explain cathodic derusting is that the electrolyte penetrates the scale and rust and then under the influence of the electric current dissociates at the metal rust interface with the liberation of hydrogen which blasts off the scale.
2. Another theory, and one recently advocated by Zapffe[11] is that the hydrogen formed enters the metal lattice at the exposed areas. These atoms then unite to form molecules within the slender metal sub-crystalline openings which apparently exist as a vast pattern throughout every metal. These occlusions of compressed hydrogen diffuse along the planes of crystalline symmetry, the gas pockets breaking from one domain to another. The movement of these gaseous occlusions to the surfaces underlying the scale adjacent to the absorption areas blasts off the rust.
3. According to another theory, water at the rust-metal interface is dissociated into $(H)^+$ and $(OH)^-$ ions by the electric current. The ions are liberated in molecular form as a gas at the insterstices of the rust layer and the excess $(OH)^-$ ions which remain react with the bare steel to form ferrous hydroxide. The compound, slightly soluble and slimy in character gradually lodges at the rust interface and thus loosens the bond between the metal and the rust, allowing the rust to drop off or be vigorously scrubbed off by the hydrogen gassing.

It is believed that the first theory can be eliminated from consideration on the basis that under it hydrogen would be evolved immediately on a rusted plate, which is not the case. Also any rust or scale film sufficiently gas tight to permit a hydrogen build up great enough to blast off the tightly adhering rust or scale would likely be sufficiently water tight to prevent the migration of the electrolyte through the rust to the metal interface in the first place. The second theory is not supported by these data in at least three respects:

1. That no hydrogen is released from the metal cathode when the electric current is discontinued as would be expected if appreciable quantities were absorbed into the metal as a result of the electrolytic process;
2. That no tendency toward hydrogen embrittlement was found; and
3. The rust layer when initially removed does not leave bare steel or residues of the original rust, but leaves a modified product different in color from the original which is still adhering to the steel.

The third theory is not supported by these data in at least two respects:

1. That immediate gasing did not occur as would be anticipated if ferrous hydroxide was being formed; and
2. In the initial rust removal the entire layer of rust was not removed and a residual slimy layer left behind as would be anticipated, but instead an outer layer of rust sluffed off leaving behind a layer of a tightly adherent and relatively hard product, which gradually softened and became removable as the electrolytic process continued.

Based on the results at hand, the most likely theory is that the electrolytic action at metal-rust interface of the cathode results in a reduction of the rust to a lower valence oxide or hydrated oxide, as illustrated by the following reactions:

$$3Fe_2O_3 + 2H \rightarrow 2Fe_3O_4 + H_2O$$
$$4Fe_2O_3 + 2H \rightarrow 2FeO.OH + 2Fe_3O_4$$

Section 3

The final phase of the electrolytic descaling process which ultimately determined its feasibility and practicability was the full scale cleaning operations undertaken by Puget Sound, San Francisco and other naval shipyards.

USS Salamonie (AO 26)

In 1942, without the advantage of the experience gained from the extensive investigations that followed, an attempt was made to descale and electrocoat two gasoline-carrying tank compartments of the *USS Salamonie (AO 26)* at the Norfolk Naval Shipyard. Although general descaling was accomplished, ineffective anode design prevented the even deposition of the calcareous deposits on the tank surfac

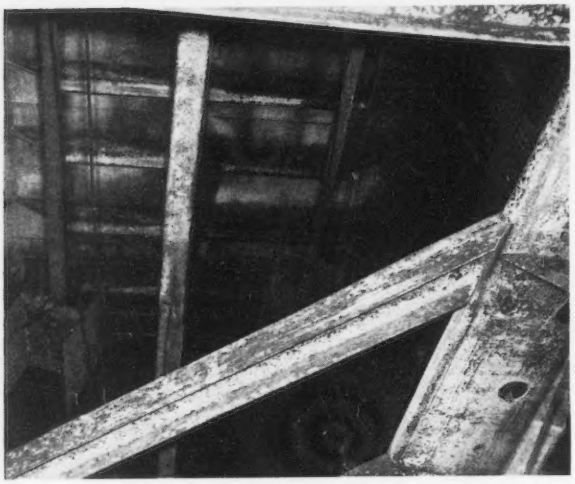

Plate 4—Typical anode location in a wing tank.

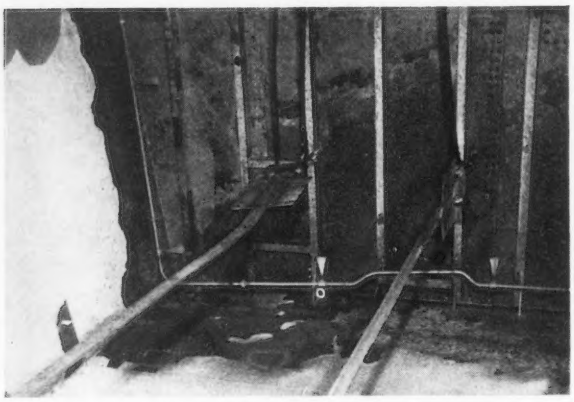

Plate 5—Corner of center line tank showing effects of uneven current distribution.

USS Cimarron (AO 22)

During 1947 and 1948, electrolytic descaling was given new impetus because of the acute shortage of aviation gasoline carrying tankers. The Navy oiler reactivation program caused an intensive exploration of economical methods for cleaning these oilers, most of which had several tanks in gasoline service, without contaminating aviation gasoline cargos. The *USS Cimarron (AO 22)* was selected as the first vessel to participate in a full scale experimental installation of the electrolytic descaling method.[10] The tests were conducted in the No. 2 centerline gasoline tank and No. 8 port and starboard cargo oil tanks. The conclusions of the test indicated that the descaling method could be practical and economical. The results showed that current values in the range of ¼ ampere per square foot applied from anodes six feet from the cathode tank surface would produce general descaling in 48 hours. The experiment pointed out that completeness of work is dependent on the design and placement of the anodes, the current density and duration of application of the current. Chlorine and hydrogen generation were a minimum since soluble steel anodes and reasonable current densities were

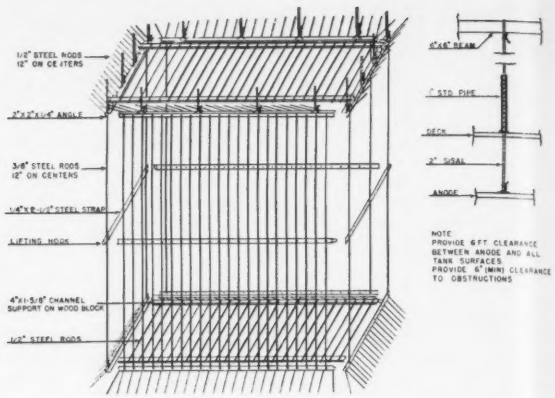

Figure 20—Showing the arrangement of steel bar anodes in centerline tanks.

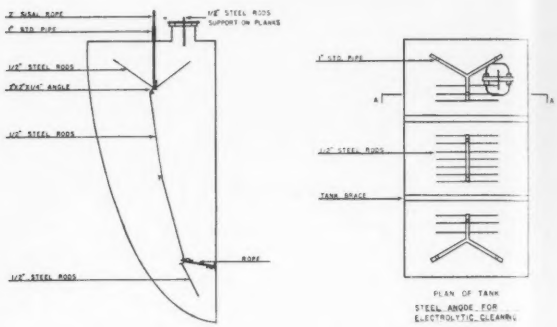

Figure 21—Showing the arrangements of anode arrangement in wing tanks.

used. In general, the experiments confirmed the fact that under normal conditions, safety precautions with respect to hydrogen, such as venting of the tanks, no smoking, welding, or burning in the immediate vicinity of the work, were adequate. The report indicated that this method could be used with light sandblasting or wire brushing to prepare a tank for painting. Also no damage to the ship structure resulted from this procedure. Plate 4 shows location of typical anodes inside a wing tank. Plate 5 illustrates the uneven distribution of current with its consequent spotty descaling in the corner of the No. 2 cargo tank of the *USS Salamonie*. This effect was consequently corrected at Puget Sound with an improved anode design. Apparently for proper descaling of tank corners, anode to cathode distances should not exceed the recommended 6-foot spacing and anodes should be extended into corners and recesses where necessary.

USS Kennebec (AO 36)

The initial experiments at San Francisco on the *USS Cimarron (AO 22)* with its attendant success motivated the Puget Sound Naval Shipyard to establish a project for adopting electrolytic descaling procedures to production methods. The Bureau of Ships assisted by supplying supporting funds. Improved anode design and fabrication, use of higher current densities and the effect of additives in the electrolyte were some of the phases of study undertaken.

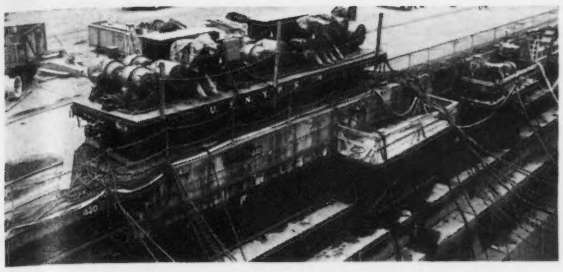

Plate 6—Motor generator assembly.

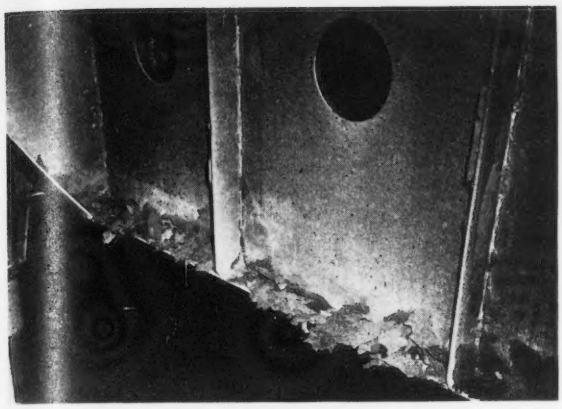

Plate 7—Deck beam after 24 hours of electrolysis. Note scale peeling from stiffeners.

The first series of full scale experiments were undertaken on the *USS Kennebec (AO 36)*.[25] Five petroleum cargo tanks were descaled using anodes closely conforming to the tank wall surfaces by means of a curtain type anode design. Generator capacity was provided to supply a relatively high current with resultant high current densities. Several factors bearing on the completeness and efficiency of descaling were investigated; namely, the effect of current reversals, the effect of acid additions to the electrolyte, effectiveness of an alkaline chromate wash in protecting the tank wall surfaces, comparison of hot fresh water washing and cold sea water washing and means of rapid flushing and sludge removal.

After drydocking the vessel, a 10-inch valve was installed at a position on the apparent low surface of the tank to facilitate emptying and desludging operations. The centerline tanks were rigged with an anode array consisting of ½-inch steel bars spaced on 12-inch centers as shown in Figure 20. The wing tanks were fitted with a different anode arrangement which is illustrated in Figure 21. The tanks were found to be descaled within a period of 36 hours and after hosing down, they were considered satisfactory for carrying aviation gasoline. Power was supplied through seven 1500 ampere DC welding generators with a resultant current density of approximately 0.4 ampere per square foot at a driving potential of 12 volts. (See Plate 6).

Cost Comparison—As compared with sandblasting of tanks, the initial electrolytic descaling of five tanks together with the additional time required for experimental work was less expensive and was accomplished in a shorter period. Principal savings over sandblasting are due to the reduction in manual labor and elimination of staging. On the basis of results obtained in experimental descaling of five tanks on the *USS Kennebec (AO 36)*, the following conclusions were made:

Plate 8—Tanks after electrolytic descaling. Dark areas are where deposit has been removed during hosing down.

1. The process is effective in descaling of cargo tanks for use in carrying aviation gasoline and is readily adaptable to production work on ships in drydock or alongside piers.
2. The operation is relatively economical and does not require the construction of staging as in sandblasting.
3. Increase in effectiveness was obtained by higher current densities and anodes conforming to the contours of the tank walls at approximately six feet clearance, provide uniformity of descaling.
4. Conversion of motor generators to provide separate field excitation eliminates need for individual resistance grid units.

Plates 7 through 10 inclusive show the effectiveness of descaling in the tanks.

Results of the Experiment

Final Tank Surface Conditions—Upon descaling of centerline tank No. 1 to bright metal, the tank walls rapidly corroded while draining down, even though an alkaline chromate wash was used. This condition was due to the treatment with acid and the current reversal which left the metal free of oxide. Because of this, it was decided to omit the use of acid and current reversals on subsequent tanks, thus permitting the calcareous deposits to remain on the cathodic tank walls. Rapid corrosion after descaling was not apparent in the remaining tanks and therefore the use of the chromate wash was discontinued. Current reversals alone were not successful in removing these calcareous deposits.

Optimum Current Density—An increase in current density was found to be effective in reducing the time and cleaning ability of the electrolytic descaling process. This was apparent in the centerline tank No. 8 where the bottom, usually the most difficult section to treat, was fully descaled when the anode current

Plate 9—Vertical keel after 28 hours' electrolysis prior to hosing down.

Plate 10—Vertical keel (same location as Plate 9) after hosing down.

density was doubled. Although higher current densities are beneficial for removal of scale the decisive factor can generally be attributed to effective current distribution by means of careful anode design, location and arrangement.

Anode Area—It was concluded that the area of the anodes was insufficient in relation to the tank surfaces (framing included) due to the heavy attack on the anodes in the No. 8 port and starboard tanks. An increase of area could be achieved by using a two-curtain anode in similar tanks.

Current Distribution—In order to preclude possible voltage drops in the anode rig which would affect even current distribution, special jumper leads were installed on the anodes of centerline tanks 1 and 2. A voltage drop survey made on one anode revealed negligible voltage variation and therefore the other tanks were wired without jumpers. The electrical connections were made to one edge of each anode rig which greatly facilitated the wiring hook-up.

Washing Down Operations—Best results were obtained in washing down operations when salt water fire mains with 2-inch fire hose and fire nozzles were utilized. High pressure fresh water from Wheeler units with special nozzles having ⅜-inch jet opening also gave good results. Hot water had the advantage of heating the side walls and drying out the tanks rapidly but was not considered necessary.

Intermittent Flushing—As a result of partial draining of tanks during inspection, a flushing and renewal

TABLE 15—Descaling Costs

	Started	Completed	Working Days	
Descaling Time	7/29	8/7	7	
Total Time, (All Work)	7/26	8/10	12	
Total Man Days	....	....	281.4	
Labor Cost* $12.50 per day			$3,517.50	
Material			560.00	
Power			150.00	
Total for 10 Tanks			4,228.00	
Average Cost per Tank*			.....	$423.00
These costs may be translated into expected costs under present economic conditions.				
Labor and Overhead at $40 per Man Day			11,256	
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* These tanks were descaled in pairs; for larger tanks (such as AO class) requiring larger anodes and individual descaling, time and material would be approximately doubled.

of sea water occurred. The effect resulting from this procedure was not readily determined during this experiment.

Hydrogen Evolution—Although hydrogen is evolved in the electrolytic descaling of fuel tanks, the possibility of trapping large volumes of the gas was eliminated by keeping the tanks full of water and allowing the hydrogen to escape to the open deck through standpipes provided for the anode supports. Hydrogen gas diffuses rapidly in the air and tests indicated that the atmosphere one foot above the manhole was non-explosive. As a precautionary measure, no smoking or welding was permitted in the near vicinity of the tank being descaled.

USS Kishwaukee (AOG 9)

Shortly after the successful descaling operations were carried out on the *USS Kennebec (AO 36)*, another tanker, *USS Kishwaukee (AOG 9)* was selected for descaling 10 of its cargo tanks.[26] The descaling method employed on this ship was similar to that on the *USS Kennebec*, except that current densities were higher and duration of descaling time was shorter. In general current densities of 0.5 to 0.7 ampere per square foot of tank surface will descale completely in 24 to 18 hours respectively. The use of a prefabricated anode design, permitting easy assembly and disassembly resulted in the savings of time and anode materials. Plates 11 and 12 show large sheets of rust descaled off tank surfaces.

A cost estimate for descaling the ten cargo tanks of the *USS Kishwaukee (AOG 9)* is given in Table 15.

Other Vessels

Further testing and modification of the electrolytic descaling process continued with experiments on the *USS Namakagon (AOG 53)*, *USS Nantahala (AO 60)*, *USS Severn (AO 61)* and *USS Taluga (AO 62)*.[27] Changes in anode spacing and design and the inclusion of an intermediate wash down and clean out during descaling operations resulted in a more satisfactory descaling process, especially for bottom areas. This work resulted in the following recommended

procedures for modifying the electrolytic descaling process:

1. Provide an intermediate drain-down operation after a minimum of 16 hours descaling followed by further descaling for 16 to 24 hours.
2. Thorough degreasing prior to electrolytic descaling is important.
3. Increase anode rod spacing from 12 inches to 18 inches and diameter from ½-inch to 9/16-inch. Insulate bottom grids from remainder of anode and feed by 2 motor-generators to give 2400 amps.
4. Increase cathode to anode distance from 4 feet to 6 feet, except bottom anode which is 5 feet.
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The sum total of the work at the Puget Sound Naval Shipyard culminated in a final report on the detailed procedure to be followed for electrolytically descaling cargo tanks.[28]

Practical Details of Electrolytic Descaling

In order to obtain consistant results, it is necessary to defuel cargo tanks and remove oil and sludge prior to performing descaling operations. A vapor injection method was developed for the purpose of rendering the tanks safe for the entry of personnel which is also suitable for removing troublesome oil residues. In this method, fuel oil deposit on the tank walls is heated by steam to reduce its viscosity. Diesel oil is then injected with steam to remove as much oil as possible through a solvent action after which the separate components of a soap are added. The fatty acid component is soluble in the fuel oil-diesel oil layer and when saponification takes place through the addition of an alkali, the oil and steam condensate is emulsified.

In brief the vapor injection consists of the following sequence of operations:

1. Ventilating when necessary.
2. Defueling.
3. Stripping.
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Following the removal of oil and sludge, the ship is then readied for electrolytic descaling.

Section 4—Summary and Conclusions

Laboratory studies indicated that time for derusting varies with the salinity of the electrolyte and the current density on the cathode. It is largely independent of temperatures within 40 to 100 F. No significant differences in derusting times could be observed between synthetic sea water and a 3 percent NaCl solution. Cathodic cleaning readily removed oleoresinous adherent paint from a sandblasted steel surface but was generally ineffective in removing rust between faying surfaces and also deteriorated aluminum cathodes. Residual deposits left on steel are mainly composed of magnesium hydroxide (white) when a sea water electrolyte is used. A black

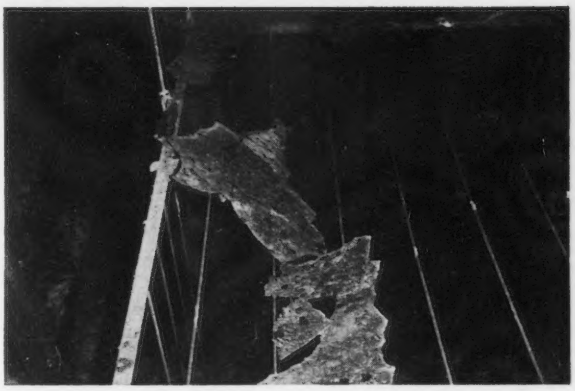
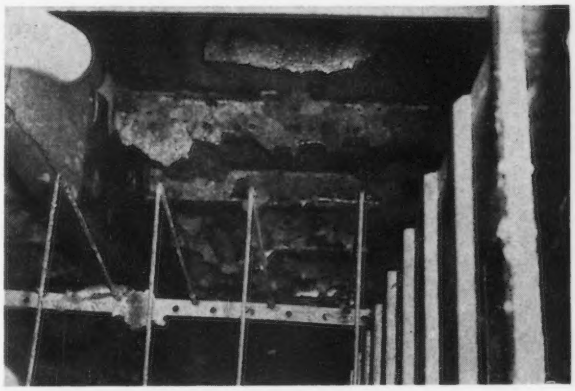


Plate 11—Tank after electrolytic descaling and draining down, showing upper corner of anode and loose sheets of rust on bulkhead.



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residual deposit of iron (Fe_3O_4 or Fe_3O_4 + FeO.OH) results from a NaCl electrolyte. Prevention of white deposits on tank surfaces during electrolysis or its rapid removal after electrolysis can be accomplished by the addition of 0.86 percent H_2SO_4 by weight to the electrolyte. White deposits cannot exist in acid solutions of pH 1 or lower. Hydrogen embrittlement does not occur on mild steel plate subjected to electrolytic descaling in sea water. Several commercial addition agents added to the electrolyte were ineffective in reducing the time for derusting. Soluble metal anodes other than steel can be used, but higher driving voltages are required to maintain the normally electronegative metals electropositive during electrolysis. Non-ferrous anodes do not prevent formation of residual deposits when electrolysis is extended beyond time required for rust removal. Insoluble anodes such as platinum act in the same manner as non-ferrous metals in regard to formation of residual deposits and in addition may extend time of derusting because of economic limitations of anode area, as well as generation of chlorine gas at the anode. Electrolytic descaling is ineffective in removing scale of the type found on brass evaporator tubes. Further, hydrogen liberated at the cathode enters into the chemical reduction of ferric oxide (Fe_2O_3) and is

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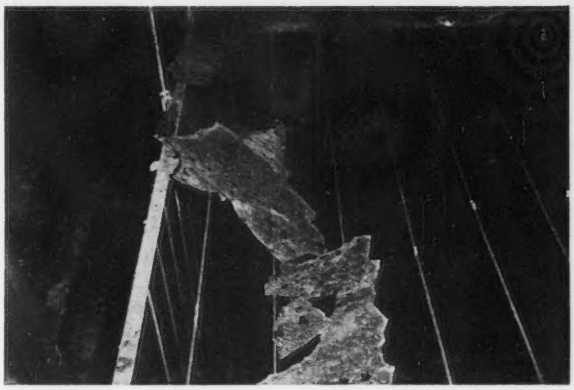

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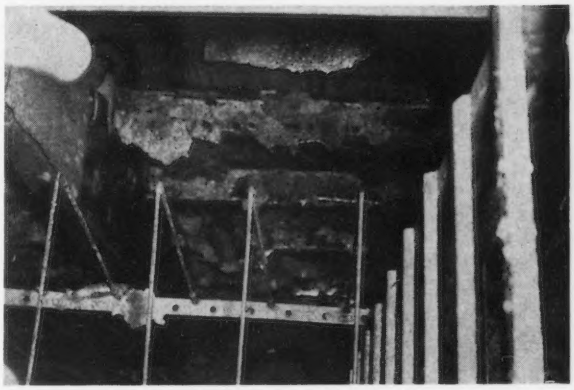

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liberated in stoichiometric quantities after chemical reduction is complete.

Electrolytic descaling is a rapid and possibly less expensive method than manual and mechanical methods for removal of heavy scale in large tanks. It has the additional advantage that no metal is removed from the tank surfaces and the descaled metal is left in a passive condition less subject to rapid rust formation. The process is applicable to large floodable voids, large structures which can be immersed in sea water and small parts which can be immersed in tanks containing the electrolyte. It has particular application in removing rust from cargo tanks, being cleaned for converting to light fuels such as aviation gasoline where contamination must be avoided. Removal of oil and sludge is a prerequisite prior to descaling operations. Essentially demountable grid anodes arranged in curtains roughly conforming to the geometry of the tank are energized by low voltage high current sources such as DC welding generators. The tank acts as the negative ground for the electrical circuit. The sea water electrolyte which fills the tank completes the circuit. The electrolysis reactions which take place during descaling electrochemically reduces the iron oxides at the metal interface and causes the scale to slough in sheets. When operating at current densities of ½ to ¾ amp. per square foot, descaling can be carried out in about 30 to 40 hours. Draining and flushing the tanks completes the operation.

Recommendations: It is recommended that:

1. The electrolytic descaling process be exploited by the marine industry.
2. An anode system be designed for a drydock which would electrolytically descale and remove old paint from a hull at time of overhaul. (The ship could be ballasted so that paint removal in way of the boot top could be accomplished.)
3. A review of surface standard requirements for precision machinery and small objects be made to determine the feasibility of reclaiming corroded equipment.
4. A method be standardized for the non-destructive cleaning of rusted panels for laboratory and field corrosion studies.
5. Research and development go forward along the following lines in order to provide wider versatility and application in many naval and industrial fields.
   a. Determine best methods of forming and stabilizing uniform adherent electrocoatings deposited from sea water in tanks and on other structures for the purposes of achieving greater corrosion resistance in service. (The British have experimented with chromate and silicate solutions for hardening purposes but have met with little success.)
   b. Develop techniques for painting over coatings of controlled character.
   c. Investigate addition of additives to the electrolyte which may produce a descaled bare steel surface suitable for painting.
   d. Investigate development of movable light-weight staging, mechanically operated on rails for coating application in tanks, which would materially reduce labor costs in applying a suitable coating after the electrolytic process.

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The authors wish to acknowledge the assistance of the many individuals in the Pearl Harbor Naval Shipyard. San Francisco Naval Shipyard, Charleston Naval Shipyard, Puget Sound Naval Shipyard, New York Naval Shipyard and the Bureau of Ships, whose combined efforts made this information available. In particular, special mention is made of the following persons:

1. The laboratory investigations were conducted at the Material Laboratory of the New York Naval Shipyard by Mr. I. H. Schwat, Electrical Engineer, under the direction of Mr. P. A. Gruber, Electrical Engineer, Supervisor of the Battery Section. The final report 5092, footnoted in Section 2, was prepared by Mr. P. A. Gruber and reviewed by Mr. H. L. Flatt, Electrical Engineer, Head of the Electricity Branch.

The work of San Francisco Naval Shipyard was supervised by Lt. George Jones, USN and Mr. Robert D. Miller, both of whom were the authors of the referenced report.[10]

The work at Puget Sound Naval Shipyard was supervised by Mr. J. F. Mills, Head of Laboratory Branch, Code 370. Shop work was supervised by Commander A. C. Lombardi, USN, Shop Superintendent. The principal investigators on the various phases of the projects were Mr. W. H. Miles, Test Engineer, Mr. G. F. Pettengill of the Chemical Engineering Unit and Mr. R. E. Canfield of the Chemical Group. Mr. J. G. Turbitt, Chemical Engineer, was associated with the hydrogen evolution study.[9]

The entire program at the Bureau of Ships was under the Administrative Direction of Commander H. H. Fox, Jr., USN.

The recommendations and opinions expressed in this article are those of the authors and not necessarily those of the Navy Department.

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Current Requirements for Cathodic Protection of Pipe Lines*

By MARSHALL E. PARKER

THE ACTUAL PROBLEM which confronts the corrosion engineer is not so much the determination of the minimum total current which will effectively protect a given section of a pipeline from corrosion, as it is the design of a system through which certain values of current are drained from certain selected points of the line to the end that the line is placed under adequate cathodic protection (some portions thereof being necessarily over-protected) at a minimum total annual cost, taking into consideration installation, operation, maintenance and certain intangibles.

Among the intangibles to be considered when designing a cathodic protection system are: reliability, or freedom from possibilities of accidental damage; minimum interference with other structures, including possible future construction and ease of maintenance and inspection, which may have a great deal of bearing on the thoroughness of inspection actually attained. These intangible considerations are not subject to precise mathematical treatment, but their importance cannot be over-emphasized as they are often the controlling factors.

There are three basic methods of determining combinations of current drainage which will effectively protect a given section of pipeline:

1) placing the line under full protection, using temporary installations;
2) placing the line under partial protection, again using temporary installations, and obtaining the requirements for complete protection by extrapolation; and
3) measuring the electrical characteristics of the line and calculating its behavior under various proposed systems of electrical drainage.

There is, of course, a fourth method of arriving at the current requirements—an estimate based on information available on the coating, the soil in which the line lies and other pertinent factors. Although this method may sound trivial, it actually is of considerable importance, for two reasons: There are situations in which it is adequate for making the decision to proceed with installation and, whenever either of the other methods is to be used, there must be *some* idea of how much current to use for the initial test.

Integration and Isolation Factors

Another two factors to be considered before a valid test can be run are *integration* and *isolation*. Obviously, it is imposible to run a meaningful test on a section of pipeline unless it is bonded into a single electrical unit. Welded steel lines offer no problems in this respect; screw-coupled lines usually are electrically continuous, although the joints may involve some resistance, but, on small-diameter pipe, some types of thread compound even may be capable of completely insulating. It is with mechanical couplings, particularly the sleeve type, that most continuity difficulties arise. Unless specifically designed for the purpose, such joints cannot be depended upon to be conductive, nor can they be depended upon to insulate. There even have been cases where a joint will open and close (electrically) like a switch, without in the least failing to perform its designed function. Before any meaningful current requirement test can be run, all such joints must be located and bonded. If they appear only after the test is begun (as often happens), then the program must be interrupted until integration can be accomplished.

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Abstract

The problem faced by the engineer seeking to cathodically protect a buried pipe line is to find the best and most economical way to drain from certain selected points on the line sufficient current to give adequate protection. Three basic methods to this end are placing the line under full protection, placing the line under partial protection and calculating the requirements for complete protection, both using temporary installations; and measuring the electrical characteristics of the line and calculating its behavior under various proposed systems.

The fourth method—an empirical estimate—is more important than its nature would indicate because certain assumptions based on observation and experience usually are helpful in arriving at a final conclusion.

Principal problems also faced by the engineer are those of securing electrical continuity where joints other than welded are used and insulating the line from other buried structures.

The author recommends a procedure involving steps such as: Determining static potentials, draining interrupted current from selected points and from data thus collected determining the relationship between polarization and driving voltage and attenuation of driving voltage; computing desired effect of combinations of drainage currents.

Also discussed are such questions as technique for making potential readings, various means of plotting data for best use, what constitutes "adequate" protection, where the electrode should be placed in making potential readings and other matters.

★ A paper presented at a meeting of South Central Region, National Association of Corrosion Engineers, Dallas, Texas, October 12-15, 1954.

The electrical *isolation* of the structure to be tested must also be established before a valid test can be run. Particularly troublesome are such massive structures as tank farms, gasoline or repressuring plants and refineries, in all of which there is a very large area of bare metal in contact with the soil. If the line in question is coated, the current demands of the foreign structure easily may be a hundred times as great as that of the line, so determining requirements of the line without first insulating it is futile.

A word of caution—it is unwise to attempt to specify location of insulated joints from an inspection of drawings alone. Far too often there are metallic elements not shown on the drawings at all, but quite capable of short-circuiting an insulated joint. Gage lines, operating lines, braces, supports, conduit and similar accessory devices frequently are offenders in this respect.

Use of Trial and Error Method

Once the two conditions of integration and isolation have been achieved—and this may well be the largest part of the project—the actual test can be initiated. The simplest method, in principle, is to put the line under cathodic protection, using temporary sources of power and temporary ground beds. Obviously this method will require a great deal of trial and error and will be prolonged almost hopelessly unless first guesses are reasonably accurate. It can be done, however and it has the advantage of requiring virtually no calculations.

A temporary ground bed ordinarily differs from a permanent one in that it has a higher resistance and a much shorter projected life—often to be measured only in hours. A temporary source of power differs from a permanent one in that it is usually a piece of portable equipment, is more flexible and adjustable and ordinarily has to have a higher terminal voltage to deliver enough current through the higher resistance of the temporary anode. Power costs, per ampere-hour thus are much higher than for the permanent system ultimately to be installed. Insofar as the pipeline itself is concerned, however, there is no difference at all. Once a line has been brought to an acceptable protective potential throughout by a set of temporary installations, then it can be depended upon that a permanent system, draining the same amounts of current from the same points on the line, also will be effective in establishing protection. Actually, the permanent system usually will do an even better job, because the effect of polarization on the line assists in the maintenance of protection.

Although attractively simple, this method is rarely used in practice, because it is far too expensive. At least two installations are needed (except for short lines) and, unless the first estimate was quite accurate, the equipment may have to be moved several times before a workable system is found—and even then, there is little assurance that it approximates the *best* system.

Alternate to Trial and Error

An obvious modification of the method just described consists of placing the line under *partial* temporary protection and arriving at the final design by extrapolation. If certain precautions are observed and careful measurements are made, accurate results may be obtained by using test currents as small as one-fifth, or even one-tenth, the magnitude of the actual currents needed for protection. Extrapolation of current values, using the same drainage points as used in the test, is fairly simple; projection of the system from a set of test currents and drain points to a different set of drain points is not quite so simple. The latter can be done, however, by a method to be described.

Measuring Electrical Characteristics

The third method mentioned involves measuring the electrical characteristics of the line and then determining by calculation the results which can be obtained by various combinations of drainage currents at various points. This approach has the advantages that all of the trial and error process takes place on paper and that enough combinations can be computed to insure that the one adopted is not only workable, but also the best possible. The major disadvantage is that it is further removed from reality; the margin of error is much greater and the uncertainty larger. Furthermore, if there are any possible interference problems involving other structures, these must be made the object of separate field investigations.

The mathematical theory covering the distribution of current and potential along a pipeline under cathodic protection is based, as are all mathematical theories, on certain assumptions of uniformity; the greater the discrepancies between assumed uniformity and actual condition of the line, the greater will be the discrepancy between calculated and actual values. When the coating on a line is excellent, agreement between theory and fact is quite good and this method may be used with confidence, but with poor or mediocre coating, it is less reliable and it is virtually useless with bare pipe or with very poor coating.

Method Is Suggested

The following method is suggested as having the advantages of near-minimum field work and only a reasonable amount of extrapolation. It may be described as being a combination of methods 2) and 3); that is, it involves only partial protection of the line and it does make use of the mathematical theory of distribution, but without the employment of complex mathematical formulae. The technique involves five steps, as follows:

1) Determine static potentials along the line.
2) Drain an interrupted current from a selected point on the line, reading "on" and "off" potentials at test points.
3) Repeat step 2) at other points, if the line is long.
4) From the field data thus determined, determine two functions; the relationship between polarization and driving voltage, and the distribution or attenuation of driving voltage. Both of these functions are determined graphically.
5) Using the functions just determined, compute the effect of any desired number of combinations of drainage currents until an optimum system is found.

1. Static potentials are merely values of the pipe-to-soil potential before application of cathodic protection current, temporary or permanent. These are needed simply as a datum of reference, in order to facilitate interpretation of later readings. Spacing

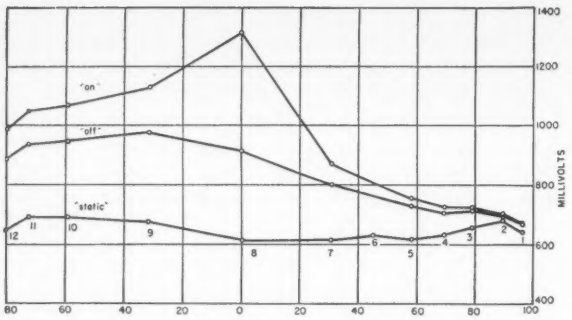

Figure 1—Longitudinal Distribution Curves. Distribution of pipe-to-soil potential along the line; the very obvious difference between the two ends of the line illustrated are attributable to a short-circuited casing on the right hand section. The horizontal unit is 1000 feet.

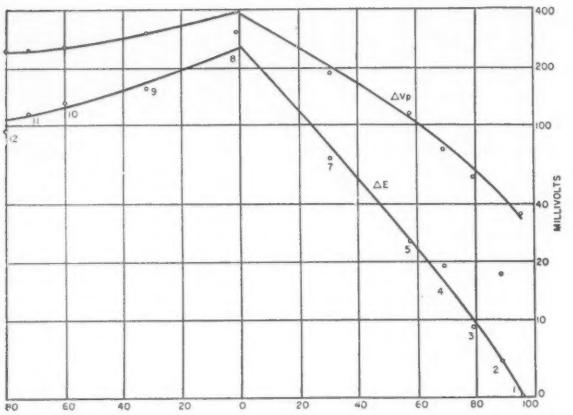

Figure 2—Attenuation curves. Driving voltage (ΔE) and Polarization Potential (ΔVρ) plotted on semi-log paper against distance along the line. For an infinitely long line, such curves should be straight lines; for a finite line ending in an insulated joint, concave upward, as in the left-hand section; and for a "grounded" section, concave downward, as in the right-hand section. The test point numbers on the first three figures correspond.

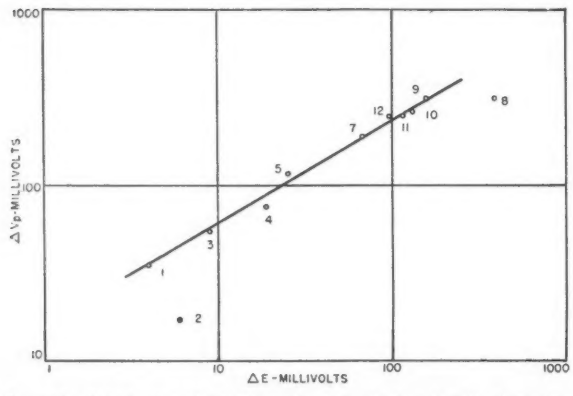

Figure 3—Polarization chart. From this plot, the functional relationship between driving voltage and polarization potential may be obtained. Test point 2 is anomalous. The explanation is found in the short-circuited casing at this location, which minimized polarization. The anomaly at point 8 is due to proximity to the anode; the apparent value of the driving voltage is too high.

at which readings should be taken must depend to some extent upon the anticipated behavior of the line. On a well-coated line, wide spacing—five or ten miles in extreme cases—may be adequate, while on a poorly coated line, the spacing may be as little as 500 feet. Often existing test leads at road crossings will supply a sufficient number of values.

2. The point selected for the initial test should be one at which it will be possible to make a permanent installation; that is, it should have low resistivity soil and available power and should be on land on which it is believed that an easement for an anode bed could be obtained. The initial value of test current used should be the least which it is believed *might* possibly be suitable. Here the estimating ability of the engineer comes into play and the better his first guess is, the less readjustment of test equipment will be required. It is important that the first value used be less, rather than greater, than the final adopted value, to avoid excessive polarization and its confusing complications. As soon as the test is fairly under way, a reading or two should be taken at or close to the drain point. If the value used is inadequate, it then can be increased with little loss of time.

When it is decided that the test value is adequate, or probably so, a full set of readings should be taken at all of the test points at which statics were read—or at least as far down the line as the effect can be detected at all. At each point, the potential should be read twice—once with the test current "on", and once with it "off". The interrupter cycle should be about one minute, and preferably the "on" period should be longer than the "off". Forty-five seconds on and fifteen off is a satisfactory combination. It is important, in taking these readings, that the copper sulfate electrode should be placed in *exactly* the same position which was used in reading the statics. The importance of this precaution is smaller the better the coating on the line; with extremely good coating, it is relatively unimportant.

As soon as these readings have been obtained, they should be plotted, along with the static potentials, on a graph such as that shown in Figure 1. The horizontal scale represents a distance along the line and the vertical, pipe-to-soil potential. Such a graph should be plotted in the field, as the data are accumulated, for often some thing will be disclosed which should alter the procedure. It should be noted that the vertical scale for this set of curves is linear; the logarithmic scale which conforms to the exponential nature of potential attenuation is applicable only to *differences* or *changes* in potential.

Very often—particularly with well-coated lines—the readings obtained at the ends of the section will be sufficiently large to be significant, in which case no further test is needed on the section. If, however, the readings become too small to be meaningful, then it may be advisable to conduct a similar test from another drainage point. This is the step 3 mentioned above.

4. From the data thus obtained, two functions can be determined; these are illustrated in Figures 2 and 3 respectively. That in Figure 2 shows the distribution or attenuation of the Driving Voltage (and the Polarization Potential) with distance along the line. In the case illustrated, there is a very obvious difference between the right- and left-hand ends of the line. Driving Voltage is defined to be the difference between the "on" and "off" readings at each particular point; it is the instantaneous effect of the test current, divested of the in-

fluence of the static potential. Polarization Potential is the difference between the "off" and the "static". It reflects the change in potential of the line brought about by the application of cathodic protection current for a (somewhat indefinite) period of time.

Figure 4 shows the theoretical attenuation of current and of pipe-to-soil potential (more accurately, of Driving Voltage) along an *infinite* line. It will be seen that both curves are straight lines on semi-logarithmic paper. In Figure 5 the curves showing the attenuation along a finite line terminating in an insulated joint are shown. The current goes to zero as the end is approached, while the Driving Voltage becomes horizontal. The curve on the left-hand side of Figure 2 reflects this set of conditions. If the line is terminated in a "zero resistance" ground, or by connection to a massive bare structure, the distribution can be had by simply interchanging the two curves in Figure 5. This is the situation portrayed in the right-hand end of Figure 2.

As has been pointed out, the mathematical expressions which describe attenuation are based upon certain assumptions of uniformity; actual lines are seldom uniform, therefore perfect agreement between theory and facts is not to be expected. However, those who abandon the question at this point deprive themselves of some very useful analytical tools, by not inquiring as to the magnitude of the discrepancies to be expected. Actually, they are often quite small, particularly when coated lines are considered. This is true because the principal variable is leakage conductance. On a bare line, this is determined almost entirely by soil resistivity, which is likely to be an extremely variable quantity. As the quality of the coating improves, the influence of differences in the soil becomes smaller and smaller, so that on a well-coated line it is not at all unusual to find virtually perfect agreement with theory. It is considered that the agreement as shown in Figure 2, an actual line and Figure 5, a theoretical curve, is very good; certainly the interpretation of the different shapes on the two ends of Figure 2 is helped considerably by the analysis.

Functional Relationship Explained

Figure 3 illustrates a functional relationship between the Driving Voltage and the Polarization Potential. This is plotted on logarithmic paper; i. e., both scales are logarithmic and both are in the same unit—millivolts. Many curves, on a wide variety of structures, demonstrate quite clearly that there is a definite function involved, but it will be left to the theoretical electrochemists to explain. When a test is conducted, not on a pipeline, but on some such structure as a refinery or plant with many buried lines or different materials, ages and coatings, the function is not clear. Instead of a fairly definite line, there is a scatter diagram involving a broad band, with many anomalous points. For a pipeline, however, it is normal experience to get a definite line, although there are usually some anomalous points. Almost without exception these can be explained; there is something abnormal about conditions at the discrepant points.

In the example shown, point No. 2, upon investigation, turned out to be at a short-circuited bare casing;

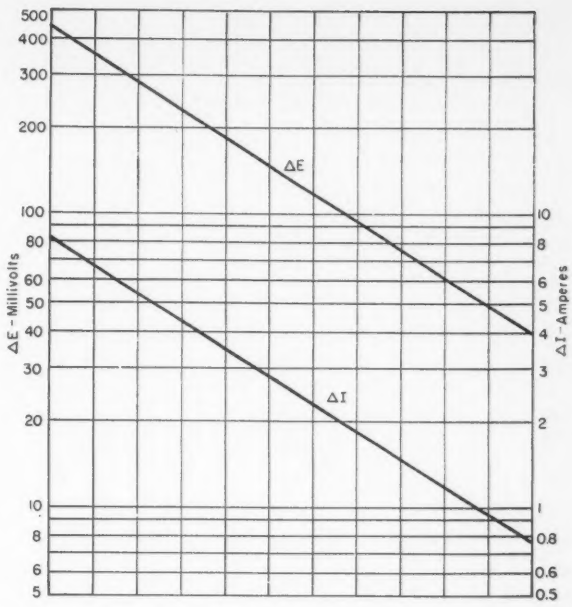

Figure 4—Attenuation curves for infinite line. The rate of decline of Driving Voltage (ΔE) and Line Current (ΔI) with distance from the drain point. The horizontal scale represents distance along the line; each division might represent as little as 500 feet (large bare line in low resistivity soil) to as much as 25,000 feet (very good coating).

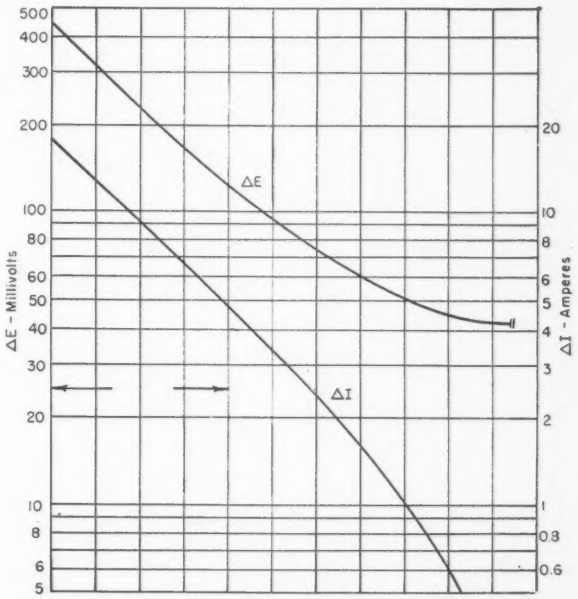

Figure 5—Attenuation curves for finite line. When a line is terminated in an insulated joint, the curves take the form shown here. The Driving Voltage becomes horizontal at the end, while the line current goes to zero. It may be observed that, with a proper choice of vertical scale, either of these curves may be expressed as the derivative of the other. If ΔE and ΔI be interchanged, the above curves apply to a line terminated in a "zero" resistance to ground.

point No. 8 (which could have been expected to be abnormal) was at the drain point itself and its reading was distorted by the proximity of the anode. Perhaps the most surprising feature of this kind of curve is that it seems to be little influenced by the variation in the total

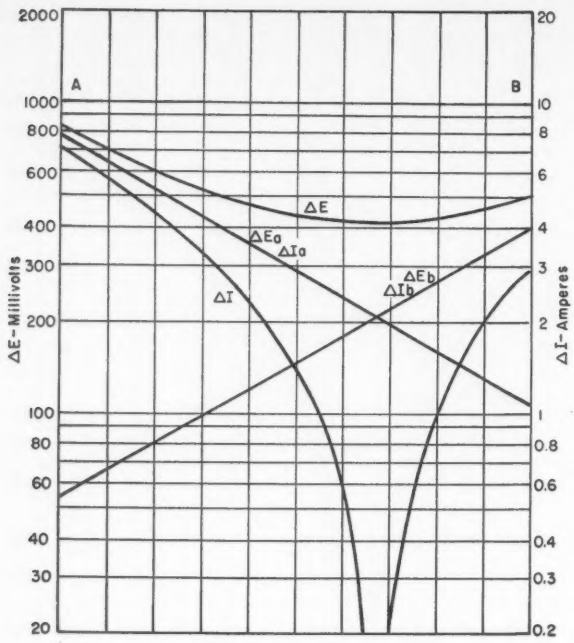

Figure 6—Attenuation curves between two drain points. The portion of the above diagram lying on either side of the point where the two straight lines cross, the Driving Voltage is at a minimum and the line current is zero is mathematically identical with the curves shown in Figure 5. In other words, an insulated joint could be inserted in the line at the point of zero line current without affecting the behavior at any point.

time during which the polarization has taken place; in the example shown, this varied from about one hour to nearly seven hours.

With these two functions in hand—and certain other data—it is possible to proceed to the design of a cathodic protection system. This can be done by assuming a set of drainage points and computing the actual pipe-to-soil potential which can be obtained throughout the line from the proposed set. Various combinations of currents and locations can be tested—all on paper—until one is found which effectively protects the line at a reasonably minimum cost. The other data needed, of course, are those which pertain to sites at which power is available and at which the soil resistivity is suitable for anode installation.

The procedure, step by step, is as follows:

5a. Select—by estimation—a set of drainage points and proposed current values guided, of course, by power and site availability and by experience.

5b. Draw, on semi-log paper, the anticipated attenuation or distribution curves for each of the drainage points separately, extending them as far as any appreciable response may be expected. This is a plot of Driving Voltage alone. The value at the drain point can be expected to be proportional to the drainage current. The slope at that point will be the same as that in the test curves. The shape will be determined by the location of the ends of the line. Although this can be done mathematically, it is usually possible to do it by purely graphical methods.

5c. Draw, this time on ordinary linear-scale paper, these same curves. Then compile for the entire length of the line section under study, a *composite* Driving Voltage curve, by adding the values from each of the separate curves from the various drainage points. This will give a plot along the line of the Driving Voltage which will be obtained with all of the proposed units in operation.

5d. Determine for each point on the line, the Polarization potential corresponding to the composite Driving Voltage at that point and add this value to the Driving Voltage. This value is determined from the Functional curve which corresponds to Figure 3.

5e. Now add to this value the Static Potential determined in the original survey. The sum of all these potentials is the pipe-to-soil potential which may be expected at each point under the proposed system of drain points and currents. By an examination of the resultant curve, it can be seen whether or not the proposed system is adequate.

5f. Repeat the above steps as often as necessary, until a system is devised which is adequate to protect the line, and whose cost is lowest (including not only first cost but also power consumption and maintenance figures.)

Agreement on Criteria Needed

Throughout preceding discussion, there has been a tacit assumption that the terms "adequate protection" and "pipe-to-soil potential" are understood. In order to define these terms, agreement must be reached on two questions: What kind of an electrode to use, and, Where to put it? Then there must be agreement on what kind of a reading shall be considered to correspond with adequate protection.

There is little need for difference of opinion about the electrode. The copper/copper sulfate electrode is widely accepted as a standard in all types of soil corrosion and cathodic protection, and in any event, results obtained with any one of a number of other reference electrodes can be translated into equivalent readings with this particular standard.

Controversy arises concerning placement of the electrode. This is most unfortunate, because the major part of this controversy is due to a misunderstanding. In the derivation of the highly theoretical attenuation equations, a number of simplifying assumptions had to be made. Among these was the assumption of the existence of an "infinite bus" or a conductor without resistance, lying parallel to the line and separated from it by a rather peculiar resistance medium—one which had a definite, measurable resistance in one direction, perpendicular to the line and an infinite resistance in all other directions. All of the potentials involved in this attenuation theory were based on potentials with respect to "remote" earth—that is, with respect to this mathematical fiction, the infinite bus with zero resistance. From this it may be deduced that, in order to obtain field data which may be expected to be consistent with the attenuation theory, a "remote" electrode should be used. The question then is, how remote?

Where to Place Anode?

Before attempting to answer this, it is well to consider electrode placement when the problem is not

agreement with attenuation theory, but the attainment of cathodic protection. It seems obvious that, since the phenomenon involved is galvanic cell corrosion (excepting stray current damage), that it is associated with currents and potentials flowing in geometrically small circuits in immediate proximity to the pipe/soil interface and that *only an electrode in this vicinity could possibly give a true picture.* There always exists the possibility a small local cell is active and only application of enough cathodic protection current to overcome the potential of such a cell is adequate to achieve full protection.

This presents a dilemma: to achieve accord with the useful mathematical theory of current and potential distribution, a remote electrode must be used. To determine whether or not cathodic protection is obtained, a near electrode must be used. But the design process just described makes use of theory and also is profoundly concerned with achievement of protection.

This dilemma is, fortunately, not as absolute nor yet as inescapable as it sounds. When coated lines are concerned, such a large percentage of the total resistance to "remote earth" lies within the coating itself, that electrode placement is not very critical. And for bare lines, or those with very poor coating, theoretical distributions seldom hold in any event. Therefore, it is a virtually inescapable conclusion that for valid and reliable results, *the electrode always should be placed close to the line.*

Upon examining the third area of needed agreement cited a further reinforcement of this decision is found. It is an unfortunate fact that, to date, no acceptable criterion of cathodic protection based soundly on electrochemical theory exists. Both of the commonly accepted criteria are empirical in origin. These are, respectively, a potential of —0.85 volt or more, with respect to a copper/copper sulfate electrode; and a *shift* in potential of 0.3 volt or more from the "static" value, again with respect to a copper/copper sulfate electrode. Both of these criteria have been used and both have been proved in the field as being adequate to eliminate or tremendously reduce leaks due to corrosion. *Both are based on the use of a near electrode.*

The term "near electrode," as used here, means one placed directly over the pipe. Actually, it would be better from a theoretical point of view to place it even closer—immediately adjacent to the pipe/soil interface. This is more laborious, however and is also open to the objection that the reading thus obtained is too highly localized. Besides, the experience upon which the empirical criterion of —0.85 volt is based is experience with an electrode placed over the pipe. In order to make proper use of criteria developed either in the laboratory or by the application of electrochemical theory, the soundest approach would be that which, by means of null circuits and two or more electrode positions, arrives at a value corresponding to that at the corroding or protected surface, but does so by means of measurements taken at the surface of the earth. Such techniques are atractive in theory, but have met with little application in practice, largely because of the complexity of instrumentation involved and the time consumed. They are still useful for the careful investigation of critical cases.

Increase of 0.3 Volt Considered

The other criterion mentioned, that of an increase in the negative potential of the line of 0.3 volt, is also based upon experience, although not quite as much. Its chief usefulness seems to be in the protection of old steel lines, whose static potential is likely to be very low—sometimes .1 or .2 volt. To raise such structures all the way to —.85 may require very substantial amounts of current and it often is felt that this much change is not required for full protection. This is a difficult question to answer, because both criteria are empirical and both are based on widely scattered and variously reported cases.

In summary, the case for the use of —0.85 volt on a near electrode as a criterion is based upon the following:

1) Many hundreds of miles of line, proved vulnerable to corrosive attack by the occurrence of actual leaks, have been protected to this level. In most cases, there has been a total cessation of leaks. In a few cases, there has been at worst a very substantial reduction, but in no case has this degree of protection been ineffective.

2) In several cases, lines have been brought to —0.85 volt, referred to a remote electrode with little or no reduction in the rate of occurrence of leaks.

It should be noted that there is no proof and little evidence, to the effect that lines cannot be protected at a potential less negative than —0.85. There is, however, a considerable body of evidence that this value is adequate.

In carrying out the system described above for determining an optimum design for a cathodic protection system, *all* of the pipe-to-soil measurements must be made consistently; that is, a decision as to what electrode and what electrode placement is to be used must be made before any of the steps can be carried out. The decision as to what criterion of protection to employ need not be made until the analysis is begun. The choices named above are based on an analytical application of what is basically empirical data. A more solidly based choice must await either further careful experimental work or a sound theory of cathodic protection.

Reference

1. All figures in this article are from "Pipe Line Corrosion and Cathodic Protection." Marshall E. Parker. 1954. Gulf Publishing Co., Houston, Texas.

DISCUSSION

Remarks by Lyle R. Sheppard, Houston:

With time cathodic protection of buried pipe lines tends to polarize the metallic surface with hydrogen and to make the immediate environment more alkaline. Both of these effects would tend to increase the soil-to-pipe electrical resistance. Is this effect considered in designing cathodic protection systems?

Reply by Marshall E. Parker:

The effect mentioned is always in the mind of the engineer who is designing a cathodic protection system, but the specific provision made for it—if any—

varies according to the circumstances. Providing for this diminution in current demand would require the design of a system whose capacity was less than that anticipated but with an available excess capacity to provide early protection. When galvanic anodes are used, this can be done by permitting unrestricted operation for an initial period and then limiting current output by means of series resistors. This is commonly done.

With rectifiers, the only way to get the initial excess capacity is to provide more than will ultimately be needed. This, too, is fairly common practice, although the excess capacity is most often thought of in the nature of a safety factor.

Another effect exists which cannot be ignored. It usually may be anticipated that pipe coating will deteriorate with time, so that the current demands of the line will increase. This is opposite to the effect mentioned and the actual net resultant may be in either direction. It is also true that the design of cathodic protection systems for pipelines is not an exact science (largely due to the fact that it simply does not pay to gather all the data which is pertinent) and so a considerable degree of over-design is standard (otherwise, cathodic protection rectifiers would not be built with so many taps.)

In summary, it may be said that corrosion engineers are aware of the effect of decreasing current demand, but that there are so many other variables present that seldom is any specific account taken to allow for it.

Cell Currents and Potentials*

By ROBERT POPE

ELECTRICAL engineers, particularly communication engineers like to reduce complicated or long electrical circuits to relatively simple equivalent circuits consisting of resistances, inductances and capacitances in parallel and series arrangements so that the equivalent circuit has the same characteristics as the circuit under investigation. A study of such equivalent circuit brings to light effects which can be expected from the actual circuit. In this study, an effort is made to apply this technique to corrosion cells. Due to the non-linear variability of the polarization phenomenon, it was found that a variable potential had to be included in the equivalent circuits to represent polarization voltage.

The work covered in this paper was started in an effort to explain cell action to electrical engineers and it represents primarily an electrical engineer's viewpoint.

In addition to the equivalent circuits, use is made of polarization diagrams to show the effects of certain cell characteristics on the cell curent and on the minimum cathodic protection current required to stop corrosion. Polarization diagrams have been used by Dr. R. M. Burns[1] and others as listed in the references.

Simple Concept of Polarization

It is not intended that this study should become involved in any controversy among electrochemists concerning polarization and current distribution. A rather simple concept of polarization is taken. For the purpose of this study, polarization is merely the change in electrode potential caused by the transfer of electricity from an electrode to an electrolyte or vice versa. The electrode potential is represented by the potential between the electrode and a half cell placed so close to it that there is no resistive effect included. Any resistive effect at the surface of the electrode is considered as part of the electrolyte resistance. To minimize confusion, the static potentials of the half cells are exactly equal to each other and are sufficiently electronegative that the electrodes are always positive with respect to them. The discussion assumes that no permanent films are created on the surface of the electrodes as a result of the current and therefore, any electrode will return to its original static potential whenever its current becomes zero. Ionic conduction through an electrolyte is considered as being similar to electronic conduction in a conductor in that it is subject to similar resistive effects.

In explaining the effect of cathodic protection, use is made of the theory of superimposed currents, which states that the net current in any part of a circuit may be the algebraic sum of several currents from different sources. For example, an electrolyte may carry a current of 100 milliamperes from an anode to a cathode. When cathodic protection current is introduced, its distribution can be considered entirely independently of the cell current. If it is assumed that 75 milliamperes of cathodic protection current go to the anode and 40 milliamperes go to the cathode, the net anode current becomes 25 milliamperes (100 ma of cell current less 75 ma of protection current) and the net cathode current becomes 140 milliamperes (100 ma of cell current plus 40 ma of protection current). This, of course requires that the direction of current be designated and for this study the direction is assumed to be from points of more positive potential to points of less positive or negative potential, through a conductor or resistance. This is reverse of the theoretical travel of electrons.

Anode Returned to Static Potential

In a simple cell consisting of one anode and one cathode, the minimum condition required to stop corrosion by means of cathodic protection is that the cathode must be polarized to the open circuit or static potential of the anode. This rule applies only if the electrical resistance of the cell circuit (both the conductor portion and the electrolyte portion) is negligi-

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Abstract

Cell action is explained to electrical engineers by analogous equivalent circuits and polarization diagrams. Adopting a simplified concept of a theoretical corrosion cell the criterion of complete cathodic protection is defined. By means of a simple galvanic cell concept and with descriptive polarization diagrams the criteria of minimum cathodic protection under certain relationships of current density between the anode and the cathode are discussed. Effect of anodic and cathodic control, the Pearson null method, similar electrodes with impressed potential, resistance of cell circuit, are covered.

Laboratory tests with lead electrodes are reported. 9 figures.

* A paper presented at the Seventh Annual Conference, National Association of Corrosion Engineers, New York, N. Y., March 13-16, 1951.

TABLE I
Legend

E — Electrode Potential (with respect to a half-cell at the electrode surface).
e — Polarization Potential
V — Any other potential, as battery potential (BV) or potential drop caused by resistance (RV)
I — Current
R — Resistance
A — Anode
C — Cathode
S — Sacrificial Anode
O — Static (0 current) Condition
Q — Equilibrium Condition
P — Protection, as Protection Current (PI)
MP — Minimum Protection Condition

Examples

CE — Cathode Potential
QCE — Cathode Potential under Equilibrium Conditions
MPAI — Anode Current under Minimum Protection Conditions (equals 0)
MPI — Minimum Protection Current, same as MPSI

ble. Under this condition, the potential of the electrolyte adjacent to the anode is essentially the same as the potential of the electrolyte adjacent to the cathode even though the electrolyte is conducting electricity. The rule also requires that there are no superimposed potentials in the cell circuit. Because of the limitations of this rule, it will not be used in this study and a more general and obvious rule will be used. This rule states that to stop corrosion, the anode must be returned to its static potential.

For use in equations and on figures, a system of abbreviations has been developed and this is shown in Table 1.

Polarization Curves

When an electrode transfers electricity to or from an electrolyte, a polarization potential is usually built up at the electrode-electrolyte junction. This is in the form of a "counter EMF," so called because it always opposes the current. Up to a certain point, which is beyond the interests of this study, polarization potentials vary with current density (or with current for a fixed size of electrode), the potential becoming greater as the current becomes greater, but the relationship is not a straight line function. Because polarization opposes the current, it makes the more positive electrode (the cathode) become less positive and the more negative electrode (the anode) become more positive. Usually cathode polarization is greater than anode polarization for any given current density.

The relationship between polarization and current can be shown on curves known as polarization curves. Anode and cathode polarization curves for a simple cell are shown on Figure 1. The anode polarization is somewhat greater than would ordinarily be expected and this is done in order to show more clearly some of the effects.

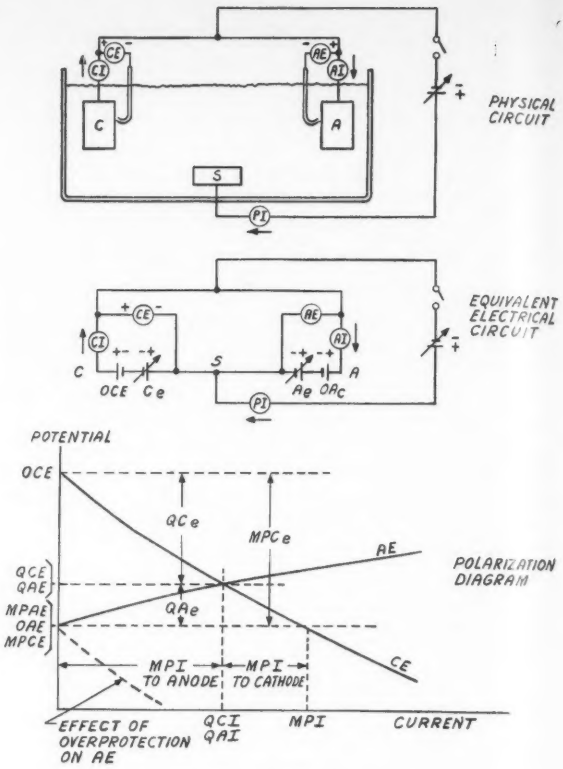

Figure 1—Simple galvanic cell.

Simple Galvanic Cell

As an introduction to the discussion, the currents and potentials in a simple galvanic cell, as shown in Figure 1, will be reviewed. At the top is a schematic diagram of the physical layout of the cell and the protective circuit. Below this is shown the equivalent electrical circuit. The fixed potentials in the cell circuit are the electrode static potentials which are not equal and the variable potentials in series with these are the polarization potentials. The meters are indicated as showing the electrode dynamic potentials which are the static potentials plus (algebraically) the polarization potentials.

In the polarization diagram, the cathode potential curve (CE) shows the cathode becoming less positive with increasing current and the anode potential curve (AE) shows the anode becoming more positive with increasing current. With the anode and cathode connected together, the cell current will be stabilized at the intersection of AE and CE. This is called an equilibrium condition and the values of potential and current under this condition are indicated with a prefixed letter Q. From the polarization diagram and also from the equivalent circuit, it is evident that

$$QCE = QAE$$

and that

$$QCI = QAI$$

In order to stop corrosion of the anode, protection current (PI) is supplied through the cathodic pro-

tection circuit and part of the protection current goes to the anode and the rest to the cathode. The protection current reduces the net anode current so that the anode potential returns along its curve. The protection current increases the net cathode current so that the cathode potential continues along its curve beyond the intersection. Since there is no resistance in this cell circuit, the following relationship must exist at all times.

$$CE = AE$$

In order to stop corrosion, the protection current must be increased until the net anode current is reduced to 0. At that time,

$$AI = O$$

and

$$AE = OAE = MPCE$$

Under minimum protection conditions, the anode's share of the protection current is equal to QAI and since the protection current is in the opposite direction to the cell current, it exactly neutralizes the cell current. The cathode's share of the protection current is equal to MPSI minus QCI. This is in the same direction as the cell current and is added to it so that

$$MPCI = MPSI - QCI + QCI = MPSI$$

or, in other words, the net cathode current under minimum protection is equal to the protection current.

In review, the following conditions obtain under minimum protection conditions of a simple galvanic cell without resistance:

1. The potential of the anode and the potential of the cathode are equal to the static potential of the anode.
2. Polarization of the anode is zero.
3. Polarization of the cathode is equal to the open circuit potential of the cell, but is negative in sign.
4. The net anode current is zero.
5. The net cathode current is equal to the total cathodic protection current.

Difference in Size of Electrodes

The polarization diagram for a simple cell can be taken to represent a condition where the anode and cathode are of equal size. In many cases of actual corrosion cells, the anode area is much smaller than the cathode area, causing the corrosion to be concentrated in the relatively small anode areas and resulting in corrosion pits on the surface. Polarization is really a function of current density and consequently if the area is increased and the current remains the same, the current density and the resulting polarization are less.

For purposes of comparison with the simple cell with equal size electrodes, another cell will be assumed similar to it, but in which the cathode area is 75 percent of the total area and the anode area is 25 percent. In such a cell, the current density due to cell current is three times as great at the anode as at the cathode. If the total electrode area, that is the cathode area plus the anode area, is the same in both

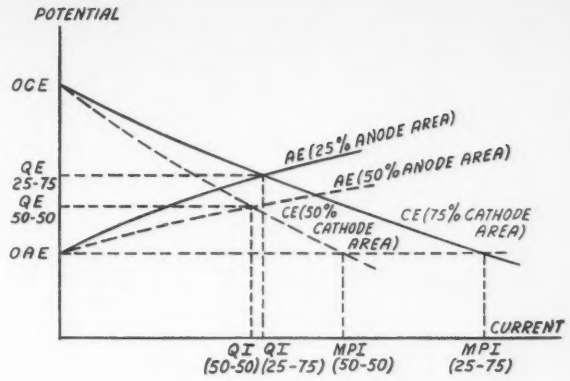

Figure 2—Effect of electrodes of unequal size. 50-50 represents equal size electrodes. 25-75 represents 25 percent anode area, 75 percent cathode area.

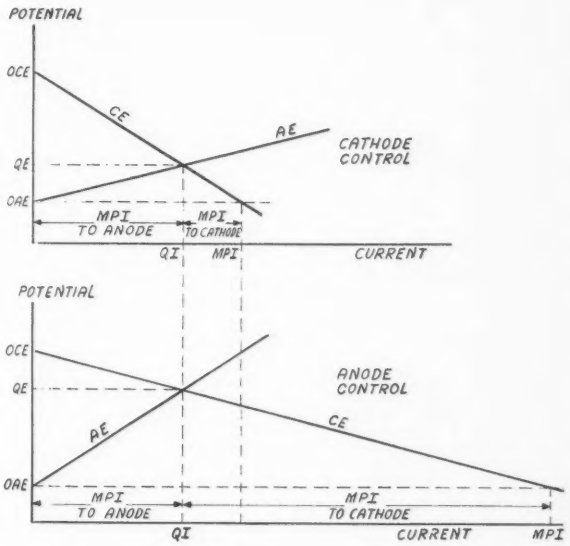

Figure 3—Comparison of cells with cathode control and anode control.

comparative cases, the anode current density and anode polarization will be greater for any given cell current, in the case of the smaller anode. Similarly, the cathode current density and cathode polarization will be less with the larger cathode area. More accurately, the anode current density will be twice as great and the cathode current density will be ⅔ as great. A comparison of the polarization diagrams for these two conditions is shown in Figure 2. It leads to the unexpected conclusion that more protection current is required to stop corrosion where the anode area is small than is required where the anode area is relatively large. Actually, the protection current requirement is more dependent on the cathode size, the larger cathode requiring greater current to polarize it to the open circuit potential of the anode. The increase in minimum protection current would not be so great if the anode polarization curve was flatter or if the comparison cells had 80 percent cathode area as compared with 90 percent.

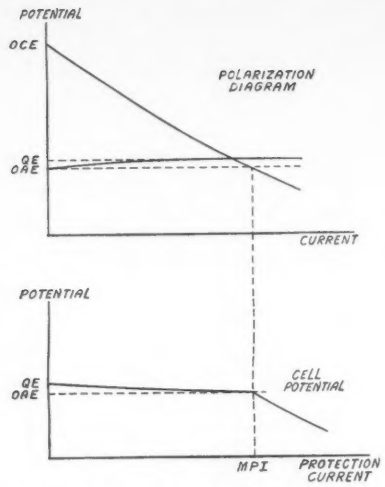

Figure 4—Change in cell potential with protection current as indicated in polarization diagram.

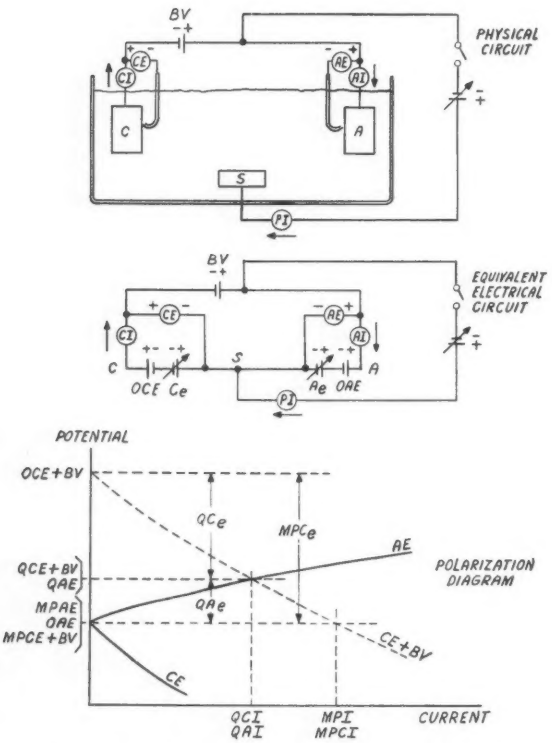

Figure 5—Cell of similar electrodes with impressed potential.

There is little difference in the equilibrium cell currents in the two comparative cases, which means that with the smaller anode, the current density at equilibrium is greater and the pitting action faster.

Effect of Anode Control

As stated previously, cathode polarization is usually greater than anode polarization for the same current density. Under such conditions, the cell is said to be under cathode control because the cathode polarization is primarily responsible for limiting the cell current and resultant corrosion. Under certain conditions, a corrosion cell may be under anode control, where the anode polarization is greater. Fortunately, this occurs only rarely in actual corrosion problems.

The effect of anode control on minimum protection current is shown in Figure 3, which compares the polarization diagrams for the two conditions. For this comparison, the same open circuit cell voltage is used for the two cases but the polarization characteristics of the anode and the cathode are interchanged. This results in the same equilibrium cell current in the two cases. It was found that using the same polarization curves as on previous diagrams resulted in a protection current so large that the diagram was too long for easy reproduction. In order to show the effect without the excess size, straight line polarization characteristics have been assumed. The important conclusion to be drawn from the charts is that under anode control, the protection current required to stop corrosion is extremely large. It is entirely possible that cathodic protection is not practical in some such cases.

Pearson Null Method

The difference in anode and cathode polarization is the basis of a method for determining the minimum current required for cathodic protection developed by the late Dr. John M. Pearson. It may be of interest at this time to take a look at the theory behind this test. In order to demonstrate it, it is necessary to assume a much flatter anode polarization curve than has been used in previous diagrams. The use of a flatter curve is entirely justified since, as mentioned earlier, the anode curves have been exaggerated in order to show better the effects of various cell characteristics.

Figure 4 shows a polarization diagram with the more customary flattened anode curve. Below this diagram is a plot of electrode potential against protection current. Since both electrodes are at the same potential, there is only one graph. At zero protection current, the electrode potential is the equilibrium electrode potential as shown on the polarization diagram. For small values of protection current there is little change in electrode potential because the anode is being depolarized. At minimum protection current, the electrodes are at the open circuit potential of the anode. When the protection current is further increased, the electrode which had been the anode becomes a cathode and follows a cathode polarization curve which is much steeper than the anode curve. This results in a change of slope of the potential curve and there is now greater change in electrode potential for a given increment in the protection current. In this example, the change in slope is very marked and this is due largely to the fact that there is no resistance in our theoretical simple cell. In a practical test, the resistive effects have to be "nulled out" and this requires rather elaborate equipment and highly developed technique. Nevertheless, this "break" in the electrode potential curve provides a means of determining minimum protection current.

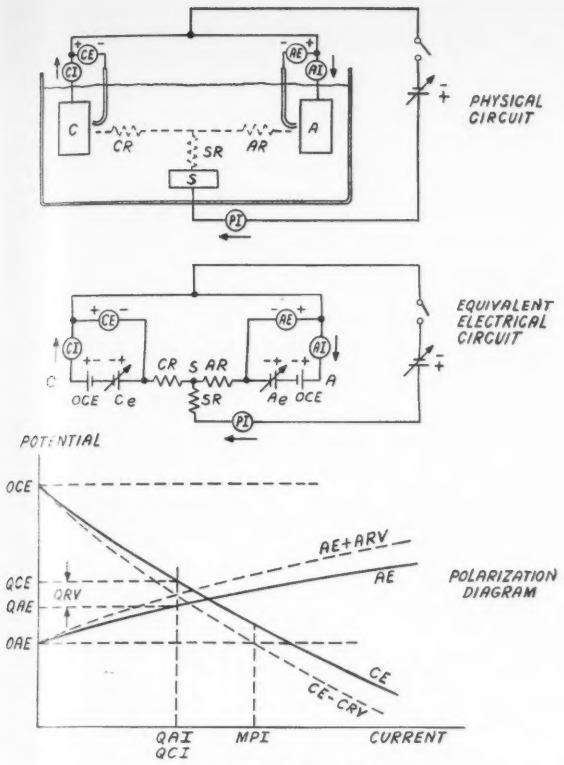

Figure 6—Galvanic cell with resistance.

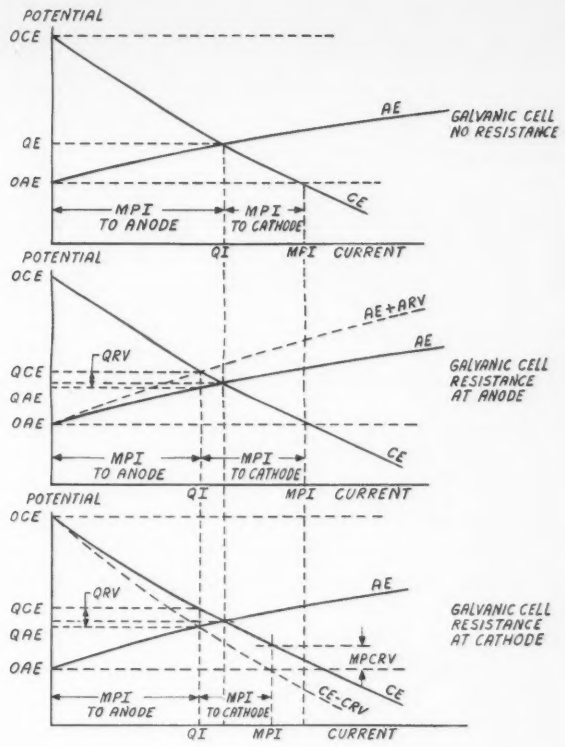

Figure 7—Effects of anode resistance and cathode resistance.

Similar Electrodes with Impressed Potential

Figure 5 shows a cell of similar electrodes with an external voltage (BV) impressed on them. The static potentials of the electrodes are equal but the potential of one electrode has been raised above that of the other by the impressed battery potential, BV. The electrode whose potential has been raised, that is, the more positive electrode becomes the anode. This seems to be the reverse of the galvanic cell where the more positive electrode was the cathode. To eliminate this apparent confusion, a more fundamental rule must be resorted to. An electrode with no current remains at its static potential. If the electrode is raised in potential above its static potential, that is, if it is made more positive, it becomes an anode and if it is lowered in potential, or made more negative than its static potential, it becomes a cathode. Such a change in an electrode's potential can be made only by connecting it to a structure of different potential. The potential of an electrode can be raised (made more positive) by connecting it to more electropositive electrode or by connecting it to the positive post of a battery whose negative post is connected to a similar electrode. Thus, it is evident that in both cases, the electrode with the raised potential becomes the anode.

The impressed potential can be considered as part of the cathode circuit, as part of the anode circuit or partly in each circuit. For this study, it will be considered as part of the cathode circuit. Thus, instead of a plain cathode, there is a cathode-plus-battery and a polarization diagram can be made, as shown in the lower part of Figure 5.

For comparison purposes, the battery voltage (BV) has been taken as being equal to the open circuit voltage of the simple cell shown in Figure 1. Comparing the diagrams will show the similarity of the two conditions, the only difference being that the significant cathode curve is really a cathode-plus-battery curve.

In a cell of dissimilar electrodes and an impressed voltage, the situation can be analyzed by considering the battery voltage as part of one of the electrodes and it doesn't make any difference which electrode is selected so long as the polarities are kept straight. If the electrode-plus-battery is more positive than the other electrode, the combination becomes the cathode circuit but if the electrode-plus-battery is more negative than the other electrode, the combination becomes the anode circuit. This rule holds even though the battery may indicate a different condition.

Resistance in Cell Circuit

Since, in all practical cases, there is some electrical resistance at the anode and at the cathode, the effects of these resistances are important. Figure 6 shows a cell with resistance. The resistance at the cathode has the effect of lowering the cathode potential by the amount of its resistance voltage (IR drop) and the resistance at the anode has the effect of raising its potential by the amount of its resistance voltage. Thus, two new curves are formed on the polarization diagram, CE — CRV and AE + ARV. The equilib-

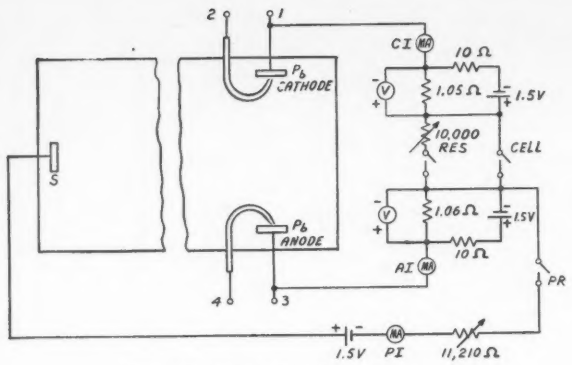

Figure 8—Lead cell polarization test.

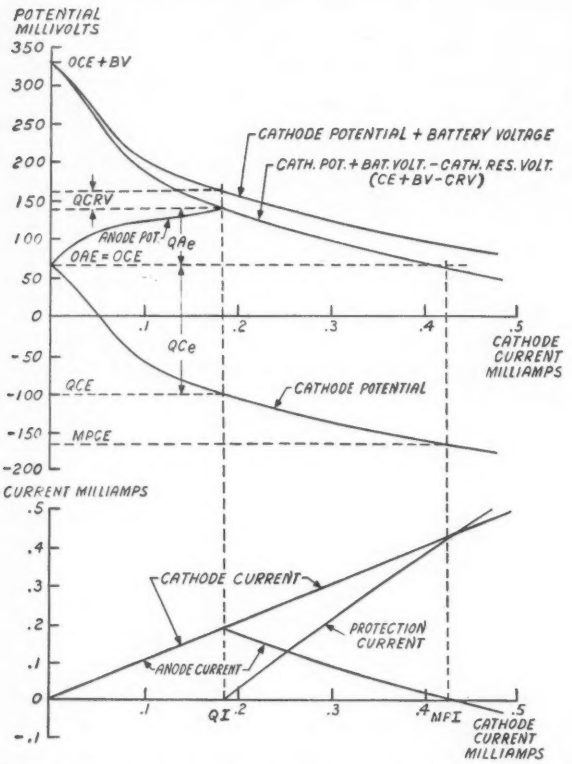

Figure 9—Result of laboratory measurements. Lead electrodes with impressed potential.

rium current is determined by the intersection of these new curves. The equilibrium current with resistance is naturally less than would obtain without resistance. Because the cell current is less, the electrodes are polarized to a lesser degree and this decrease in polarization potentials is made up in the resistance voltages.

The effect of resistance on protection current is different depending on whether the resistance is in the anode branch of the circuit or in the cathode branch. For the purpose of analyzing these effects, it can be assumed first that all of the resistance is in the anode branch, and secondly, that all the resistance is in the cathode branch. These are shown in Figure 7.

When all the resistance is at the anode, the minimum protection current is exactly the same as if the anode had no resistance. This is because, at minimum protection, there is no net current at the anode and therefore no current through its resistance to create an IR drop. Nevertheless, this anode resistance does affect the distribution of the protection current, causing a greater portion to go to the cathode than in the case of a cell with no resistance. This greater current provides the additional polarization of the cathode to overcome the resistive voltage at the anode under equilibrium conditions.

When all of the resistance is at the cathode, the distribution of the protection current is again affected, but in this case, the cathode gets a smaller portion. This serves to reduce the anode current to zero with less protection current than would be required with no resistance in the cell. With less minimum protection current, the cathode is polarized less, but with cathode resistance, it is not necessary to polarize the cathode to the static potential of the anode because the resistive drop has the effect of adding itself to the polarization. The amount of minimum protection current going to the anode is the same as when the resistance was at the anode because the equilibrium anode current was the same in both cases.

In review, resistance in any part of the cell circuit reduces the equilibrium current and therefore the rate of corrosion. Resistance in the anode branch does not affect the minimum protective current requirement but resistance in the cathode branch reduces the minimum protective current requirement. It is interesting to note that resistance in the conductor portions of the electrodes has the same effect as resistance in the electrolytic portion.

Laboratory Measurements

In order to check in a limited way, the conclusions drawn from these theoretical considerations, a test run was made in the laboratory using two lead electrodes about 2 inches square, lead-lead chloride half cells and the circuit shown in Figure 8. About .26 volt was applied to the electrodes, half on each side of the cathodic protection connection, to keep the conductor portions of the two branches of the protection circuit of equal resistance. Before applying protection current, the cell current was controlled by a 10,000 ohm variable resistance. This permitted controlling the cell current to obtain points on the polarization curves for values of cell current less than the equilibrium current. After all of this resistance was cut out, the switch marked "Cell" was closed and equilibrium conditions were measured. Protection current was then applied in small increments until the anode current reversed. Results of these measurements are shown in Figure 9. When the anode current reached zero, the anode was only 5 millivolts from its original static potential. The test tank was not large enough to permit the measurement of resistive voltages separately at the anode and cathode and the total resistive voltage is shown as affecting the cathode.

References

1. R. M. Burns. The Corrosion on Metals. I, Mechanism of Corrosion Processes. *The Bell System Technical Journal*, 15, 20-38 (1936) January.

U. R. Evans. Metallic Corrosion, Passivity and Protection, 2nd Edition, p. 348, 1948, Longmans, Green & Co.

R. H. Brown and R. B. Mears. Cathodic Protection, The Electro-chemical Society. Preprint 81-19, 1942.

W. A. Wesley and R. H. Brown. Fundamental Behavior of Galvanic Couples. Corrosion Handbook, H. H. Uhlig, Editor, 1948.

J. M. Pearson. Null Methods Applied to Corrosion Measurements. *Trans. Electrochem. Soc.* **81**, 485 (1942).

Publication 55-3

Some Corrosion Inhibitors—*A Reference List*

*A Report of Technical Unit Committee T-3A on Corrosion Inhibitors**

THE TECHNICAL Committee on Corrosion Inhibitors formerly known as TP-9 and now identified as T-3A has prepared a list of corrosion inhibitors for various uses. This list has been prepared from literature references and no attempt has been made by the committee to screen the inhibitors for relative merit or effectiveness. The committee does not consider this to be by any means a complete list of corrosion inhibitors.

The purpose of publishing the list in its present form is to provide a starting point for anyone with a new corrosion problem in a field not familiar to him. It is hoped that this list will steer such a person to the proper literature and to possible chemicals for his use.

In compiling this list the committee agreed to include only corrosion inhibitors which were described in a readily available publication. An attempt was made to include all inhibitors described in articles published in trade or technical journals, but undoubtedly the coverage is incomplete. For this reason a number of inhibitors which are in common use today were not included because no published literature other than manufacturers' bulletins was found on these materials.

Abstract

Chemical and trade names, sources of supply, utility classes in which useful, material with which effective and literature references for 68 inhibitors and classes of inhibitors are given. This list, consisting only of inhibitors for which literature references are available outside of manufacturers' literature, is conceded to be incomplete. Suggestions for additions and changes of presentation are solicited by the originating committee.

Some consideration was given to the inclusion in this tabulation of preferred environment as regards pH and temperature and also recommended dosage in parts per million. However, it was considered by the committee that inclusion of this data might be hazardous because the conditions under which a particular inhibitor would be used might be widely varying from those published.

The committee disclaims any responsibility for effectiveness of the inhibitors listed and offers this list merely as a convenience to the corrosion worker.

The committee will welcome suggestions for modification of the format of this listing for future publications and also will welcome information on inhibitors not included in this list which should be included in later compilations.

* Robert R. Wise, National Aluminate Co., Chicago, chairman.

Corrosion Inhibitor Reference List

Legend of Utility Classes (Useful In)

A Acids
B Brine (or Salt Water)
C Cooling Waters
D Potable Waters
E Steam Condensate Lines
F Petroleum Fuels
G Gas (and Gas Condensate Wells)
H Oils (Mineral)
I Oil (Crude)
J Food Products
K Paints
L Volatile
M Miscellaneous

Item	Chemical Names	Trade Names	Sources	Useful In	Effective With	References
1	Acids, stearic, naphthenic and 16 others	Same	Chemical Suppliers	H	Fe	Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan.
2	Allyl isothiocyanate			A		Chemical Abstracts, Vol. 46, No. 11, 4983[h]
3	Alumohemicellulose			A		Chemical Abstracts, Vol. 46, No. 12, 5509[a]
4	Amine Soaps			H	Fe	Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan.
5	Amines, octadecyl and others	Same	Chemical Suppliers	H	Fe	Ind. & Engr. Chem., Vol. 41, No. 1 137-144 (1949) Jan. Powers Engr., Vol. 54, No. 6 61-63. (1950) June.
6	Ammonia	NH_3	Chemical Suppliers	E I, L	Fe, Cu, Brass	Oil & Gas J., Vol. 48, No. 27, 238 (1949) Nov. 10. Corrosion, Vol. 7, No. 9, 312-315 (1951) Sept.
7	Ammonium hydroxide		Chemical Suppliers	G	Fe	AIME, Pet. Tech., Vol. 10, No. 4 (1949) Natural Gasoline Assn. of America, Corrosion Research Project Committee Reports, Dec. 7, 1945, March 6, 1946.
8	Aniline, diethylaniline, p-phenylenediamine 2-naphthylamine, phenyl 2-naphthylamine, pyridine, quinoline (and B) naphthoquinoline, 2,4 (and 2,6) dimethylquinoline, ethyl-quinolinium bromide, acridine, acridine orange, acridine red, acriflavine, euflavine, proflavine, petroleum sulfonates, sulfonated castor oil.			A	Fe	T. P. Hoar, Pittsburgh Intern. Conference on Surface Reactions, 127-34 (1948).

Corrosion Inhibitor Reference List—Continued

Legend of Utility Classes (Useful In)

A Acids
B Brine (or Salt Water)
C Cooling Waters
D Potable Waters
E Steam Condensate Lines
F Petroleum Fuels
G Gas (and Gas Condensate Wells)
H Oils (Mineral)
I Oil (Crude)
J Food Products
K Paints
L Volatile
M Miscellaneous

Item	Chemical Names	Trade Names	Sources	Useful In	Effective With	References
9	10-Anthraquinone			M	Fe	Chemical Abstracts, Vol. 43, 4207[b,f]. Doklay Akad. Nauk, SS&R, Vol. 63, 685 (1948); Vol. 64, 91 (1949).
10	Arsenite $\frac{As_2O_3}{NaAsO_2}$			A	Carbon Steels	Corrosion, Vol. 3, No. 8, 406-414 (1947) Aug.
11	Bone Oil	Same	Chemical Suppliers	G	Fe	See Ref. 7, NGAA, 1149, Vol. III, Page 146.
12	Calcium Carbonate	Same	Deposited from water on addition of lime or soda ash.	B, C, D	All Metals	J. Amer. Water Works Assoc., Vol. 28, 1500 (1936). Ind. & Engr. Chem., Vol. 37, No. 9, 842-846 (1945) Sept.
13	Calcium Hydroxide	$Ca(OH)_2$	Chemical Suppliers	C, D	Fe, Zn, Cu, Brass	Corrosion Causes & Prevention, 2nd Edition, 361-366 (1935).
14	Carbon Disulfide	Same	Chemical Suppliers	G	Fe	Proc. 26 Ann. Meeting API, Sec. IV Prod. (Prod. Bull. No. 232), Page 11 (1946).
15	Carbon Monoxide	CO		M	Fe (Stainless)	Ind. & Engr. Chem., Vol. 32, No. 11, 1490-1494 (1940) Nov.
16	Chromates		Chemical Suppliers	B, C, G, H, I, K	Fe, Zn, Cu Brass	Ind. & Engr. Chem., Vol. 41, No. 11, 2376-2382 (1949) Nov Oil & Gas J., Vol. 47, No. 37, 83-87 (1949) Jan. 13.
17	Chromates	Same	Chemical Suppliers	G	Fe	Oil Weekly, Vol. 123, No. 5, 17-22 (1946) Sept. 30. Oil Weekly, Vol. 123, No. 6, 30-34 (1946) Oct. 7.
18	Chromates	Same	Chemical Suppliers	G	Fe	See Ref. 7, NGAA, 1149, Vol. V, page 128-131; NGAA, 11150, Vol. VII, page 68-72. World Oil, Vol. 129, No. 9, 160-168 (1949) December.
19	Chromates and Caustic	Same	Chemical Suppliers	G	Fe	World Oil, Vol. 129, No. 3, 29 (1949).
20	Corexit		Humble Oil Co.	I	Fe	Oil & Gas J., Vol. 49, No. 40, 95-97 (1951) Feb. 8.
21	Dibenzyl Sulfide Thiocarbanilide			A	Fe	Chemical Abstracts, Vol. 44, No. 11, 4852[a].
22	Dibenzyl Sulfoxide			A	Iron Nickel	Chemical Abstracts, Vol. 46, No. 16, 7502.
23	Dodecylpyridine—HCl			A		Chemical Abstracts, Vol. 46, No. 18, 8592[i].
24	Mepasin-sulfamido Carboxylic Acid	Emulphor STH	General Aniline & Film Corp.	A	Fe	Corrosion, Vol. 6, No. 7, 225-231 (1950) July.
25	Ethylamine and its substituted derivatives such as bromoethylamine			A	Fe	Physics and Colloid Chem., Vol. 55, 180-187 (1951).
26	Extract of Linseed Meal				Fe	Applied Chemistry (USSR), Vol. 19, 140-147.
27	Glycerol mono-oleate (and similar esters)	Same	Chemical Suppliers	H	Fe	Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan.
28	Hydrocarbon-sulfamido carboxylic acid	Emulphor STH (Mepasin) (Emulsifier STH)	Gen. Aniline & Film Corp.	A, B, F, I	Fe, Mg, Al	Corrosion, Vol. 6, No. 7, 225-231 (1950) July). Ind. & Engr. Chem., Vol. 41, No. 11, 2616-2622 (1949) Nov.
29	Inorganic Halides especially NaI			A	Fe	Corrosion, Vol. 6, No. 10, 344-346 (1950) Oct.
30	Kontol	Same	Tretolite	F	Fe, Cu, Brass	Petro. Processing, Vol. 7, No. 2, 190-197 (1952) Feb.
31	Kontol No. 115	Same	Tretolite	G	Fe	Oil & Gas J., Vol. 45, No. 27, 86-87 (1946) Nov. 9. See Ref. 7, NGAA, 1149, Vol. V, page 83-110.
32	Kontol No. 118	Same	Tretolite	G	Fe	See Item No. 14 See Ref. 7, NGAA, 1149, Vol. V, page 83-110.
33	Lanolin	Same	Chemical Suppliers	H	Fe	Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan.
34	Lecithin	Same	Am. Lecithin Co.	F	Fe, Al	News Ed. Amer. Chem. Soc., Vol. 19, 575 (1941).
35	Magnesium (Metal)	Same	Chemical Suppliers	G	Fe	See Ref. 7, NGAA, 1649, Vol. V, page 199-201; NGAA, 1148, Vol. IV, page 104-109.
36	Mercaptobenzo thiazole	(Rokon) (Captax)	Vanderbilt	F	Fe	Oil & Gas J., Vol. 40, No. 44, 172-175 (1941) Nov. 6.
37	Molecularly Dehydrated Phosphates and Chromates	Orocol	W. H. & L. D. Betz	B, C	Fe, Zn, Cu, Brass	Oil & Gas J., Vol. 49, No. 43, 52-62 (1951) March 1. Ind. & Engr. Chem., Vol. 44, No. 8, 1770-1774 (1952) Aug. Corrosion, Vol. 6, No. 10, 331-340 (1947) Oct.
38	Molecularly Dehydrated Phosphates and Ferro Cyanides	Nalco No. 33	Nat. Aluminate Corp.	B, C	Fe, Zn, Cu, Brass	Oil & Gas J., Vol. 49, No. 43, 52-62 (1951) March 1.
39	Molecularly Dehydrated Phosphates and Organics	Phosphoglucosate	D. W. Haering, Wright Chem. Company	B, C	Fe, Zn, Cu, Brass	Oil & Gas J., Vol. 49, No. 43, 52-62 (1951) March 1. Ind. & Engr. Chem., Vol. 30, No. 12, 1356-1361 (1938) Dec.

Corrosion Inhibitor Reference List—Continued

Legend of Utility Classes (Useful In)

A Acids
B Brine (or Salt Water)
C Cooling Waters
D Potable Waters
E Steam Condensate Lines
F Petroleum Fuels
G Gas (and Gas Condensate Wells)
H Oils (Mineral)
I Oil (Crude)
J Food Products
K Paints
L Volatile
M Miscellaneous

Item	Chemical Names	Trade Names	Sources	Useful In	Effective With	References
40	Molecularly Dehydrated Phosphates and Silicates		E. F. Drew	C, D	Fe, Zn, Cu, Brass	Corrosion, Vol. 8, No. 12, 402-406 (1952) Dec.
41	Naphthenic Acid	Same	Chemical Suppliers	G	Fe	Corrosion, Vol. 3, No. 3, 121-138 (1947) March. See Ref. 7, NGAA, 21046, Vol. III, page 148-149, 186.
42	Naphthoquinoline O-tolylthiourea			A	Fe	T. P. Hoar, Pittsburgh Intern. Conference on Surface Reactions, 127-134 (1948).
43	Nitrite, dicyclohexylamonium	VPI-260	Shell Oil Company	L	Fe	Corrosion, Vol. 7, No. 9, 284-294, (1951) Sept.
44	Phosphates, hexameta, Na & Ca	Micromet	Calgon Inc.	C, D	Fe, Zn, Cu, Al, Brass	Ind. & Engr. Chem., Vol. 37, No. 8, 724-735 (1945) Aug.
45	Phosphoric Acid Esters		Chemical Suppliers	H		Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan.
46	Potassium Carbonate	Same	Chemical Suppliers	G	Fe	NGAA, (1946) March 6.
47	Potassium dichromate			A	High Cr Steels	Science Reports of the Research Inst., Tohoku University, Ser. A, Vol. 2, 209-215 (1950) April.
48	Rosin amine-ethylene oxide condensates			A		Corrosion, Vol. 7, No. 6, 180-185 (1950) June. Corrosion, Vol. 7, No. 11, 403 (1951) Nov.
49	Soaps (20 described) Chromium		Chemical Suppliers	H M	Fe Fe	Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan. Journal Science Indus. Res., (India), Vol. 4, 449 (1946).
50	Sodium Benzoate	Same	Chemical Suppliers	B, C	Fe	Journal Soc. Chem. Indus. (Br.), Vol. 66, 137. Chem. & Ind. (Br.), Vol. 53, 1194 (1951).
51	Sodium Benzoate				Fe	Chemical Abstracts, Vol. 43, No. 18, 6962[b].
52	Sodium Bicarbonate	Same	Chemical Suppliers	G	Fe	See Ref. 7, NGAA, 1548, Vol. IV, page 216-220.
53	Sodium Carbonates	Same	Chemical Suppliers	G	Fe	See item No. 14. Corrosion, Vol. 2, No. 4, 188-194 (1946) Oct.
54	Sodium Hexametaphosphate	Calgon	Calgon, Inc.	B, C, D	Fe, Zn, Cu, Brass, Pb	Corrosion, Vol. 8, No. 11, 381-390 (1952) Nov. Ind. & Engr. Chem., Vol. 32, No. 12, 1572-1579 (1938) Dec.
55	Sodium Hydroxide	Same	Chemical Suppliers	G	Fe	See Ref. 7, NGAA, March 6, 1946. Corrosion, Vol. 2, No. 4, 195-198 (1946) Oct.
56	Sodium Hydroxide	NaOH	Chemical Suppliers	C, D	Fe, Zn, Cu, Brass	Ind. & Engr. Chem., Vol. 37, No. 8, 724-735 (1945) Aug.
57	Sodium Nitrate	Same	Chemical Suppliers	C, H, F	Fe, Zn, Cu, Brass, Al	Journal Electrochemical Soc., Vol. 93, 63 (1948). Ind. & Engr. Chem. Vol. 35, 358 (1943).
58	Sodium Nitrite	Same	Chemical Suppliers	G	Fe	Corrosion, Vol. 3, No. 3, 121-138 (1947) March. Corrosion, Vol. 2, No. 4, 188-194 (1946) Oct.
59	Sodium septa	Nalco No. 918	Nalco	C, D	Fe, Zn, Cu, Al, Brass	Ind. & Engr. Chem., Vol. 37, No. 8, 724-735 (1945) Aug.
60	Sodium Silicate	Same	Phila. Quartz Chemical Supplier	C, D	Fe, Zn, Cu, Brass	Ind. & Engr. Chem., Vol. 30, No. 3, 348-351 (1938) March. Ind. & Engr. Chem., Vol. 44, No. 8, 1765-1769 (1952) Aug.
61	Sodium Silicate	Same	Chemical Suppliers	G	Fe	Corrosion, Vol. 2, No. 4, 188-194, (1946) Oct.
62	Sodium Sulfite	Same	Chemical Suppliers	B, C	All Metals	Petro. Processing, Vol. 7, No. 5, 620-622 (1952) May. J. Amer. Water Works Assoc., 39 (1121) (1947).
63	Sorbitan Esters		Chemical Suppliers	H	Fe	Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan.
64	Sulfonates, Barium Ammonium	RD-119	Chemical Suppliers Sinclair Res. Labs.	H F	Fe Fe	Ind. & Engr. Chem., Vol. 41, No. 1, 137-144 (1949) Jan. Oil & Gas J., Vol. 39, No. 28, 340-344 (1950) Nov. 16.
65	Tetraphospho-glucosate		W. D. Hearing	C, D	Fe, Zn, Cu, Al, Brass	Ind. & Engr. Chem., Vol. 37, No. 8, 724-735 (1945) Aug.
66	Thiodiglycol			A	Fe	Applied Chem. (USSR) (Zhurnal Prikladnoi Khimii) Vol. 24, No. 3, 283-288 (1951).
67	Turkey Red Oil	Same	Chemical Suppliers	G	Fe	Corrosion, Vol. 3, No. 3, 121-138 (1947) March.
68	Vogel's inhibitor (unspecified composition)			A	Fe	Korrosion u. Metallschutz, Vol. 19, 297-305 (1943).

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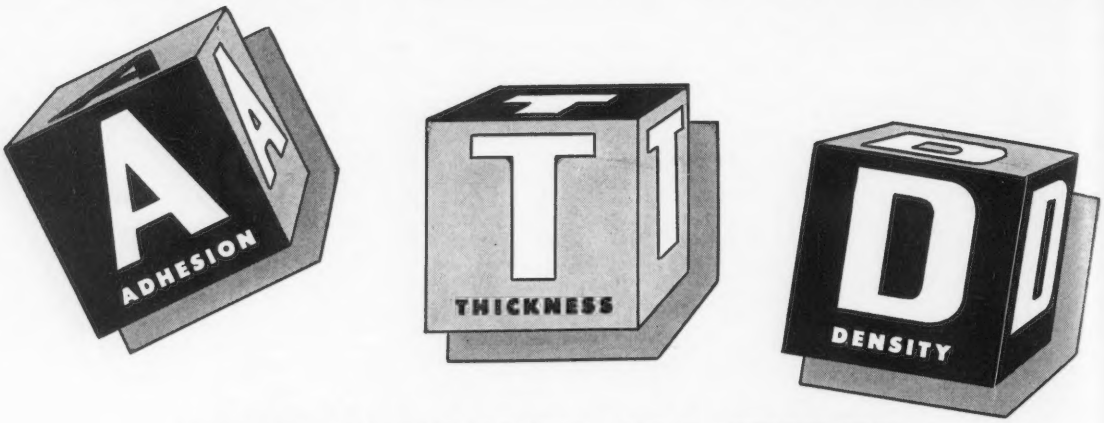

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NACE News

NACE Cooperates in Corrosion Short Courses

Shreveport Section Outlines Program For Fifth Event

Shreveport Section NACE and Centenary College, Shreveport, La. are holding their fifth annual corrosion control short course May 5-6 at the science building of the college. The course is designed primarily for superintendents, foremen, field men and engineers not regularly engaged in corrosion work.

The $10 registration fee includes two noon meals and a buffet supper.

The tentative program has been announced as follows:

Thursday, May 5

8:00 am—Registration.
9:00 am—Introduction.
9:45 am—Fundamental Causes of Corrosion.
10:30 am—Causes and Mechanics of Internal Corrosion.
11:20 am—Intermission.
11:30 am—Corrosion Control of Oil and Gas Wells.
12:30 pm—Lunch. Centenary College Cafeteria.
1:30 pm—Stainless Steels and Their Applications.
2:30 pm—Coating Inspection Practices in the Field.
5:45 pm—Fellowship Hour.
6:45 pm—Buffet Supper.

Friday, May 6

8:45 am—Insulating Materials and Practices.
9:30 am—Various Applications of Potential Measurements.
10:15 am—Intermission.
10:25 am—Corrosion Experiences in a Chemical Processing Plant.
11:00 am—Operation of a Cathodic Protection Unit.
11:40 am—Role of the Field Foreman in Corrosion Control.
12:30 pm—Lunch.
1:30 pm—Round table discussion on corrosion and corrosion control.

Miami Section Hears Cathodic Protection Talks

A meeting of the Miami Section of the NACE was held February 4 at the Blue Flame Room of the Peoples Water and Gas Company.

Joe Prime opened the meeting and introduced the speakers. E. P. Atkinson and Thomas H. Griggs, U. S. Navy Aqueduct, talked on the aqueduct from Florida City to Key West, its protection and problems. Joe Frink, Florida Power and Light Company, discussed cathodic protection of underground systems and Joe Prime, Florida Power and Light Company, related experience with corrosion mitigation on Florida Power and Light Company's system. A question and discussion period followed.

DR. J. S. LONG addresses Chicago Section February 15 on corrosion design.

Design Against Corrosion Is Discussed at Chicago

Predetermined Design Against Corrosion was subject of a talk by J. S. Long, chemical director of Devoe and Raynolds Co., during the February 15 meeting of NACE Chicago Section. Approximately 110 members attended. L. W. Ewing, Standard Oil Co. (Indiana), was master of ceremonies.

Dr. Long stressed building equations on variables and their relations in study of corrosion and felt it time that intensive study be made on 21 pure metals. He suggested a comprehensive series of tests on some 13,000 panels made of various metals and alloys as well as iron having controlled amounts of carbon and pointed out that variables should be coordinated and combinations diagramed. He explained that facts must be determined on heat treatments and/or coatings to obtain protection from corrosion and emphasized that science and mathematics must be teamed in the study.

As an example of good protective coating practice Dr. Long recommended careful sandblasting, primer of epoxy resin with 2½ pounds of zinc chromate per gallon applied in two coats in which second coat may have aluminum and final coat of alkyd resin having any desired pigment with total paint thickness being .008 to .01 inches. While treatment may cost as much as 32 cents per square foot, it may last 32 years if outer layer is renewed every five to seven years, thus saving steel, the important material, he said.

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NACE Abstract Card Service consists of about 2000 2-row punch cards a year with abstracts of corrosion literature printed on them. They are cross-indexed and punched by topics.

Wide Variety of Topics Scheduled for 4-Day Vancouver Meeting

A 4-day Corrosion Short Course will be held at Vancouver, British Columbia April 19-22 inclusive. The course, sponsored jointly by the Department of Chemical Engineering, University of British Columbia and the NACE Vancouver Section, will cover a wide range of topics.

Atmospheric and underground corrosion, marine exposures, boiler water treatment, inhibitors and fundamental reactions are among the topics to be discussed by a faculty, most of whom are NACE members. A general corrosion discussion session is scheduled also.

Ian D. G. Berwick, of the British Columbia Research Council at the University of British Columbia, Vancouver 8, Canada, is registration chairman. The fee for the course has been set tentatively at $20. Accommodations for a limited number available on the university campus may be reserved in advance. The telephone number of the registration chairman is Vancouver, Alma 1156.

Lecturers and their topics will be:

Morris Cohen, National Research Council, Ottawa, fundamentals; and inhibitors.

W. F. Fair, Jr., Koppers Co., Inc., Tar Products Div., Verona, Pa., coal tar coatings.

Daniel Markoff, Electro Rust-Proofing Corp., Monrovia, Cal., cathodic protection fundamentals.

William R. Schneider, Pacific Gas & Electric Co., Berkeley, Cal., cathodic protection practice.

J. Carson, Pacific Naval Laboratory, Esquimalt, B. C., marine applications of cathodic protection.

A. Jackson, Alchem, boiler water corrosion and water treatment.

Wayne Z. Friend, International Nickel Co., Inc., New York City, atmospheric corrosion.

Aaron Wachter, Shell Development Company, Emeryville, Cal., design from the corrosion standpoint.

M. J. Pryor, Kaiser Aluminum and Chemical Corp., Spokane, Wash., aluminum as a construction material from a corrosion standpoint.

Carroll M. Wakeman, Los Angeles Harbor Dept., Wilmington, Cal., new materials for marine construction.

A general corrosion problems discussion session will be held and a film on stress corrosion cracking shown.

S E Region Meets May 5-6

The annual spring meeting of Southeast Region NACE is scheduled to be held in Birmingham, Ala., May 5-6. Fred R. Blankenship, Jr., Southern Natural Gas Co., is program chairman.

TENNESSEE UNIVERSITY CORROSION CONFERENCE registrants are shown here during the March 1-3 sessions. The 52 registrants heard a program consisting of discussions on corrosion matters ranging from atmospheric corrosion through discussions of the fundamentals of metals and alloys.

Plastics Discussed by Genessee Valley Section

Approximately 90 members and guests attended a joint meeting and dinner of the Genessee Valley Section and Rochester Chapter, AIChE at Rochester Moose Home. Raymond B. Seymour of Atlas Mineral Products Co. spoke on Plastics for Corrosion Resistant Applications. He briefly discussed the various types of plastics commercially available.

A series of approximately 100 slides was used to illustrate various uses for plastics in corrosion resistant applications. A discussion period centered principally about the use of coatings followed his talk.

Payment of 1955 Membership Dues

In order to avoid interrupted mail and missed copies of CORROSION all NACE members who have not done so already are urged to remit their 1955 MEMBERSHIP DUES before March 31. Association by-laws require that the names of those whose dues are not received by March 31 be dropped from the membership mailing list.

Epoxy Resins Is Topic at Permian Basin Session

The 45 members and guests attending the February 14 meeting of Permian Basin Section at the Lincoln Hotel heard H. C. Owens of Coast Paint and Lacquer Company, Houston, present a paper on "Epoxy Resins; Their General Characteristics and Uses."

Harold Winston of the Gulf Oil Corp. was elected secretary-treasurer for the 1954-55 term to replace Dr. A. A. Alberts. T. L. Modgling, Aquaness Corp., was named chairman of the 6th Biennal Permian Basin Corrosion Tour.

Detroit Hears Analysis of Water Treating Gadgets

Approximately 35 members and guests attending the February 15 meeting of Cleveland Section heard B. Q. Welder, Hall Laboratories, present a paper on Practical Performance of Water Treating Gadgets. Mr. Welder supplemented his talk on fraudulent water treating devices with samples of four gadgets marketed within the past five years. He said promotional literature on these devices making claims such as elimination of scale and rust, creating of smoother water and use of less soap had received wide publicity in leading technical magazines and newspapers. Mr. Welder exposed these claims by proving there is no practical basis to the theory used to explain the action that supposedly occurs in the gadgets.

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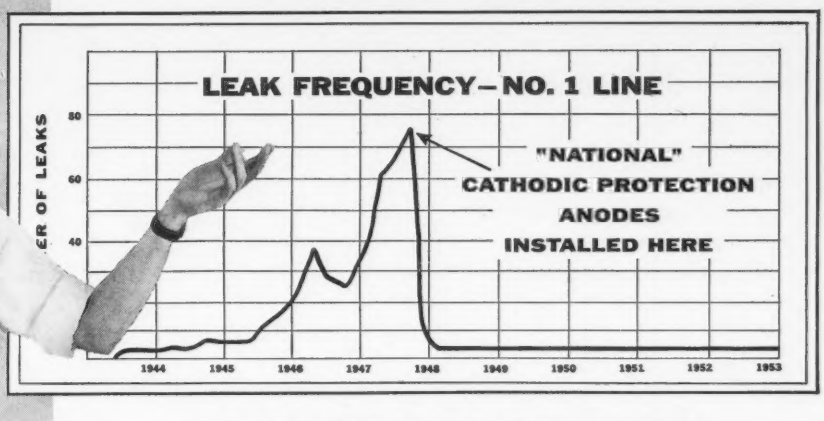

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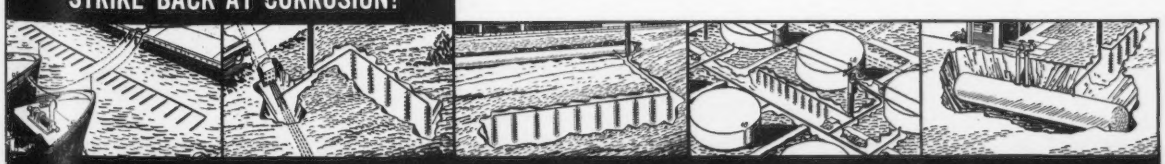

Detroit Section Presents Corrosion Panel at Ventilation Conference

Detroit Section NACE presented a corrosion panel at the Industrial Ventilation Conference held at the Kellogg Center on the Michigan State campus in East Lansing, Mich. on February 14. J. D. Guttenplan, Chrysler Corp., N. A. Kerstein, The Detroit Edison Co., L. W. Gleekman, Wyandotte Chemicals Corp. and E. V. Ivanso, Detroit Testing Laboratories, Inc. were participants.

Designing for Corrosion Protection was title of a discussion by Frank L. Whitney, Jr., Monsanto Chemical Company during a joint dinner meeting held by Detroit Section and the Electrochemical Society at the Engineering Society of Detroit on February 24. Approximately 150 members of both organizations attended.

Corrosion Resistance of Concrete in Chemical Plant Environments is title of the section's April 14 dinner meeting scheduled at the Engineering Society of Detroit. Representatives of the Universal Atlas Cement Co., the Truscon Laboratories and Portland Cement Association will participate.

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Besides magazines in the United States, articles or digests of articles in Corrosion have been published in periodicals in Belgium, England, France, Germany and Japan.

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Catalytically Cured Organic Coatings Covered at Sabine-Neches Session

F. J. Ploederl, Wisconsin Protective Coating Co. spoke on Catalytically Cured Organic Coatings during the February 24 meeting of Sabine-Neches Section. Thirty-four members and guests heard Mr. Ploederl discuss phenolic coatings, their modifications and advantages and disadvantages of modified phenols. Catalysts used with various types were listed and formulations of straight phenolics, epoxy and furanes were discussed. Slides were presented as well as results of tests conducted.

W. F. Oxford, Jr., Sun Oil Co. general arrangements chairman for the 1956 South Central Region Meeting scheduled in Beaumont announced meeting dates to be October 3-5. Committees to prepare for the meeting will be appointed later.

NACE MEETINGS CALENDAR

Apr

6 Southern New England Section. Topic to be announced.

6 Niagara Frontier Section. Will cover plastics field.

7 Pittsburgh Section. William J. Ruano, attorney-at-law, will speak on Highlights on Patents and Trade-Marks.

19 Chicago Section. Two movies, "Must it Rust?" by Hot Dip Galvanizers Assn. and "The Big Crossing" on pipe line crossing of Straits of Mackinac are scheduled.

26 Genessee Valley Section. Annual meeting and election of officers.

May

4 Niagara Frontier. Annual business meeting and election of officers.

5 Pittsburgh. A Materials Engineer in the Chemical Industry by Dr. L. W. Gleekman, Wyandotte Chemical Corp., Mellon Institute, Pittsburgh.

11 Metropolitan New York. Regional meeting. Topic to be announced. Hotel Statler, 33 St. & Eighth Ave., New York City, 10 am.

12 Kanawha Valley. Topic to be announced. Huntington, W. Va.

13 Philadelphia. Topic to be announced. Poor Richard Club, Philadelphia. Dinner: 6:30 pm; meeting, 8 pm.

16 or 21—Lehigh Valley. Plant visitation.

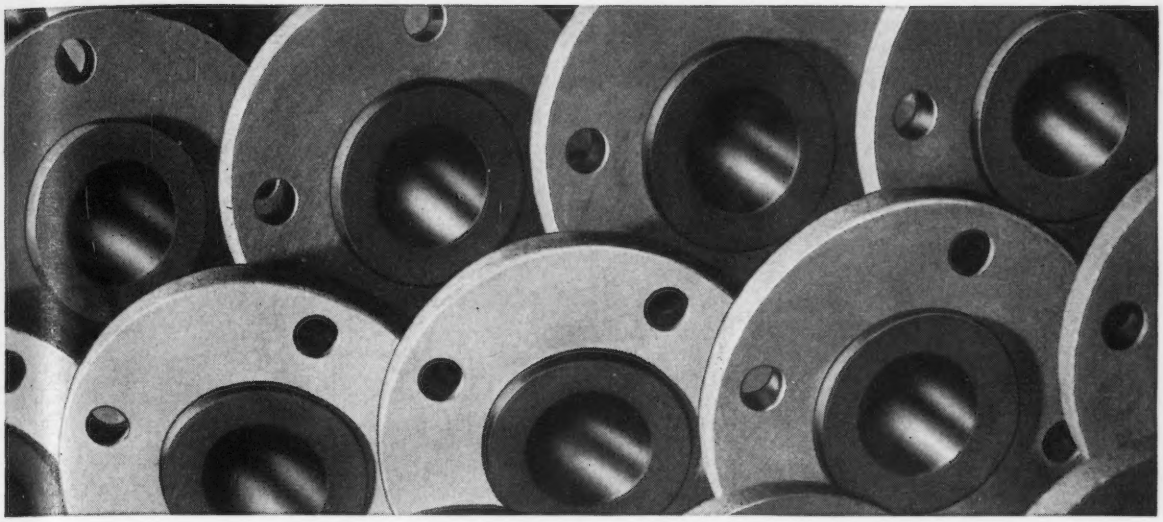
17 Chicago Section. Annual Corrosion Roundtable.

18 Greater Boston Section. Hotel Beaconsfield, Brookline, Mass.

AIChE Meeting Is Held

Design and Development of Sealless Pumps by D. P. Litzenberg and H. T. White, Chempump Corp., Philadelphia was included among general papers presented during Technical Session No. 1 held during the American Institute of Chemical Engineers' Louisville national meeting scheduled March 20-23.

DOW



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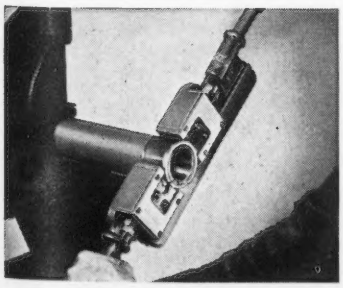
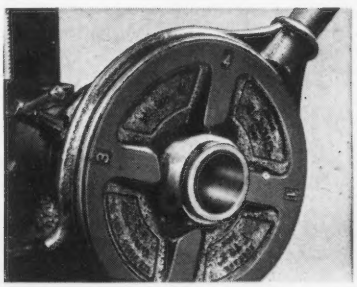


A Beaver Cutter cuts away the end of the steel pipe so that 3/16" of the saran lining is extended. This assures a tight seal after a flange is applied and connected with another flange.



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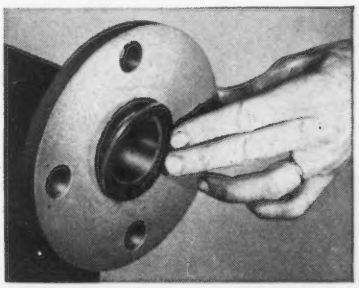

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REPORT ON THE ELEVENTH ANNUAL CONFERENCE

Committee Meetings Highlight Chicago Sessions

NEW ASSOCIATION OFFICERS: left, Frank L. Whitney, Jr., Monsanto Chemical Company, St. Louis, president; right, W. F. Fair, Jr., Koppers Co., Inc., Tar Products Div., Westfield, N. J.

NACE BOARD OF DIRECTORS at its meeting Sunday, March 6 preceding the opening of the Eleventh Annual Conference at Chicago's Palmer House.

PUBLICATION COMMITTEE members at a March 7 meeting at Chicago were: (Back to camera) T. P. May, The International Nickel Co., Inc., New York, incoming chairman; left to right, R. B. Hoxeng, U. S. Steel Corp. laboratories, Pittsburgh; Norman Hackerman, University of Texas, Austin; Ivy M. Parker, Plantation Pipe Line Co., Atlanta, Ga.; R. D. Misch, Argonne National Laboratory, Lemont, Ill.; Aaron Wachter, Shell Development Company, Emeryville, Cal.; Arthur W. Tracy, American Brass Co., Waterbury, Conn. and John E. Loeffler, Thornhill-Craver Co., Houston. Also present but concealed behind Mr. Loeffler were J. W. Ryznar, National Aluminate Co., Chicago, Arvil B. McKee, Aluminum Research Laboratories, New Kensington, Pa., present representing R. H. Brown of the same firm and A. B. Campbell.

Groundwork Started On 12th Conference At New York in 1956

Meetings of technical committees highlighted the NACE 11th Annual Conference and Exhibition at Chicago March 7-11. The usual varied program of technical papers was given also and the exhibitoin included many well-arranged presentations.

By a preliminary count, registration was 1632, somewhat more than the predicted attendance.

Early work on the New York 12th Annual Meeting was reported by several officials appointed for this event. President Whitney named the following:

Kempton H. Roll, Lead Industries Association, New York, General Conference Chairman.

Clark Bailey, Johns-Manville Co., Exhibits Chairman.

W. Z. Friend, International Nickel Co., Inc., New York technical program committee chairman. Mr. Friend indicated his plans include the same symposia as were presented at the Chicago 1955 meeting plus the addition of one or more symposia on plastic materials, metallurgy or instrumentation.

It was tentatively agreed by the board that emphasis be placed on the international character of the New York meeting by designating it the "International Corrosion Conference" and that it would be helpful to call the exhibition "The Corrosion Show." These suggestions were advanced by Mr. Roll.

Mr. Roll's plans call for encouraging the attendance of persons from Europe and South America.

Consideration will be given to holding the exhibition open for one night during the meeting.

Exhibits Exert Strong Attraction at Meeting

Exhibits that were a strong incentive to skip the important technical sessions were presented by 84 firms at the Eleventh Annual Conference. The exhibition occupied the whole of the Palmer House's Exhibition Hall and a portion of the foyer off the fourth floor registration desk. Exhibitors reported the interest of registrants was high in the numerous new products and developments presented.

The exhibitors also honored the registrants with the traditional Fellowship Hour, which was attended by more than a thousand lighthearted guests.

1959 Conference Is Set

The 1959 Fifteenth Annual Conference and Exhibition of the National Association of Corrosion Engineers will be held at the Sherman Hotel, Chicago. This decision was reached at a meeting of the NACE board of directors March 6 in Chicago.

The 1956 meeting will be in New York; 1957 in St. Louis and 1958 in San Francisco.

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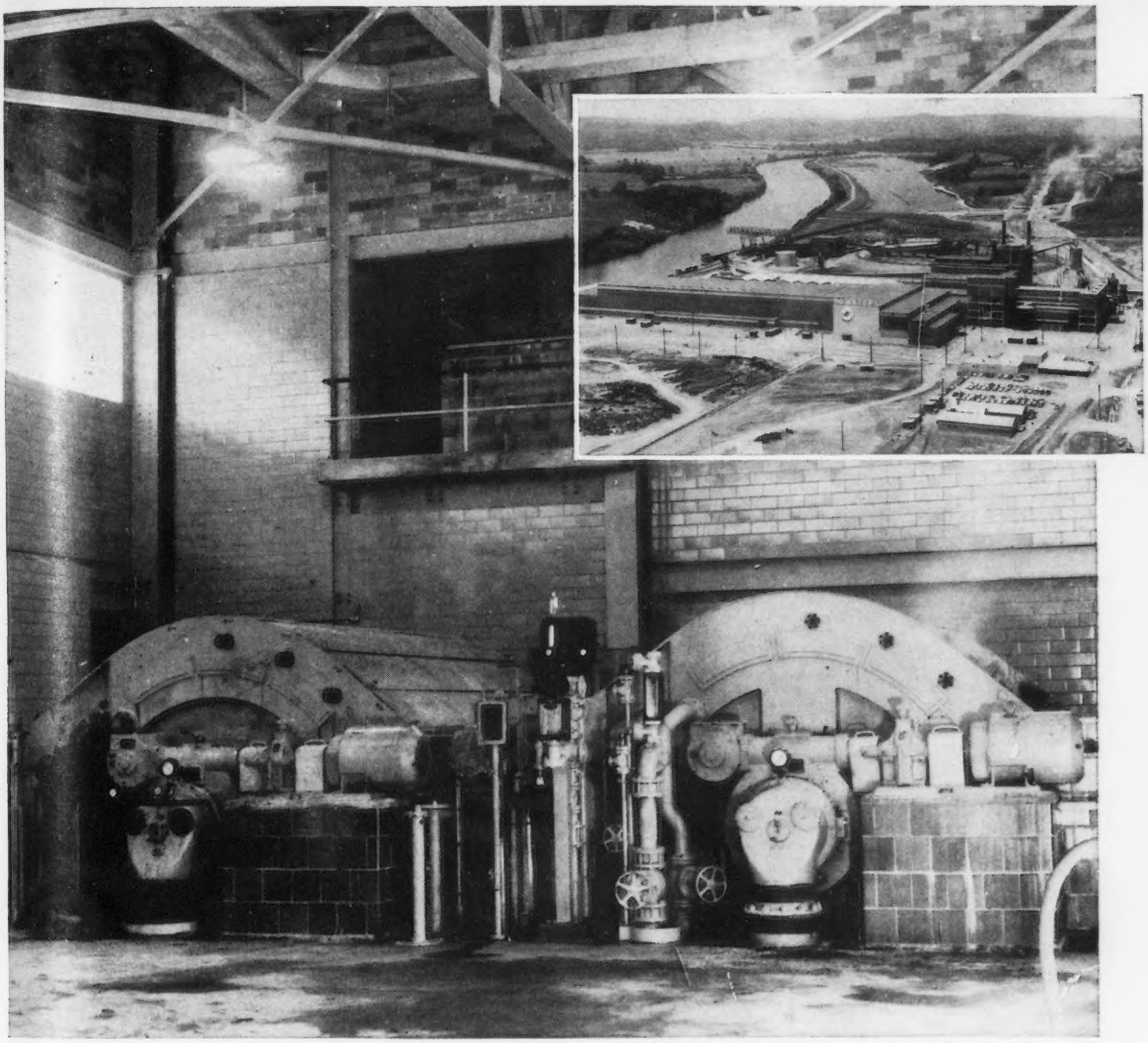

Coatings for **Impco** bleach washers were made from BAKELITE Vinyl Resins by **Socony Paint Products Company,** Metuchen, N. J.

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Five New Directors Join Board at Chicago Meeting

Five new directors took office during the NACE 11th Annual Conference at Chicago, March 7-11. They are: Robert H. Kerr, Los Angeles, representing Western Region; C. G. Munger, West Gate, Cal., representing corporate members; O. E. Murrey, Tulsa, Okla., representing active members; Robert R. Pierce, Philadelphia, representing corporate members and W. H. Stewart, Beaumont, Texas representing active members.

Mr. Kerr is with Southern California Gas Co., Mr. Munger with Amercoat Corp., Mr. Murrey, Midwestern Engine and Equipment Co., Mr. Pierce with Pennsylvania Salt Manufacturing Co. and Mr. Stewart with Sun Pipe Line Co.

Mr. Murrey fills the unexpired term of W. F. Fair, Jr., elected to the vice-presidency.

Full Program Is Held For Ladies at Meeting

Attendance at the Don McNeill Breakfast Club radio show, fashion shows and sightseeing tours featured the ladies' program during the Eleventh Annual Conference at Chicago. Included also were an informal brunch, two luncheons and the annual Fellowship Hour and banquet.

•

Back issues of Corrosion for 1954 and many issues of prior years are available.

Issuing Certificates To Past Chairmen Approved by Board

Certificates will be made available for purchase by sections and regions for awarding to past chairmen, it was decided at a meeting of the outgoing NACE board of directors May 6 in Chicago. The board met on the day preceding the opening of the Eleventh Annual Conference and Exhibition at The Palmer House.

Certificates of membership also will be available for purchase by members, the board decided. It also was agreed that a specially designated membership card would be given annually to corporate member representatives.

Other decisions at the session included:

Technical committees will be encouraged to suggest research projects which may be called to the attention of foundations making grants in aid.

No expenditures over a year old will be reimbursed to sections.

Regions and sections must make financial reports annually to the executive secretary before March 1 on funds received from the association.

Active membership applications will require signatures of two sponsors.

Specific items of information will be requested of persons applying for membership in the association.

A new schedule of prices was set up for the sale of multiple copies of Bibliographies of Corrosion.

Decisions made by the board at its meeting Friday, March 11 included:

A new policy on publication of NACE material was adopted.

The executive committee will consist of Messrs. Brannon, Fair, Wachter, Best and Whitney.

The 1955 NACE Yearbook will be distributed free to members.

The board authorized a change of policy whereby 25 copies of their articles will be sent to authors of technical papers in the technical section.

Payment of 1955 Membership Dues

In order to avoid interrupted mail and missed copies of CORROSION all NACE members who have not done so already are urged to remit their 1955 MEMBERSHIP DUES before March 31. Association by-laws require that the names of those whose dues are not received by March 31 be dropped from the membership mailing list.

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- ☐ forming dies
- ☐ guide rolls
- ☐ mattress molds
- ☐ tire molds
- ☐ ribbon blenders
- ☐ cone blenders
- ☐ hoppers
- ☐ casting molds
- ☐ coated glass tape
- ☐ miniaturized stators
- ☐ distribution transformers
- ☐ miniaturized relays

Other applications (please list) _____

AT SOME OF THE SOCIAL EVENTS during the Chicago Conference: Upper left, G. R. Olson, United Gas Pipe Line Co., Shreveport, and Mrs. Olson with her back to the camera; upper right, Irwin C. Dietze, City of Los Angeles; Mrs. Aaron Wachter; Frank E. Davie, Shell Oil Co., Los Angeles; Aaron Wachter, Shell Development Co., Emeryville, Cal., back to camera; lower left, C. P. Larrabee, United States Steel Corp., Vandergrift, Pa.; H. H. Uhlig, Massachusetts Institute of Technology, Cambridge; R. S. Dalrymple, Reynolds Metals Co., Louisville, Ky.; lower right, a group of ladies in the ladies' parlor.

Classified Industrial Directory Work Started

Work has begun in earnest on a classified industrial directory to be published with and included in the 1956 NACE Yearbook. This was reported to the publication committee during its meetings May 7 and 9 at Chicago during the Eleventh Annual Conference at Chicago. Among the items discussed were:

The 1955 NACE Yearbook probably will be issued in June. A recommendation was made that the mailing addresses of members be incorporated in the alphabetical list and that names only be published in the geographical list.

The Publication Committee has no objections to the inclusion of color advertising pages in Corrosion if they appear preceding the inside front cover.

Existing policy on free positions available advertising by companies restricts them to two consecutive insertions per year for employees only.

It was recommended that a proposal for periodical advertising be prepared for presentation in support of a request for an appropriation in the budget for 1956.

Membership of NACE will be canvassed to determine need for issuing a 10-year index to Corrosion technical literature.

Requests that NACE prepare and publish a manual on cathodic protection and a primer on corrosion for use by field men were referred to the Technical Practices Committee for consideration.

Corrosion Abstract Cards issued during the years 1952 and 53 will be reprinted to supply the demand for back issues.

Members of the Publication Committee and others in the association will be sent a questionnaire asking for ideas on long range policies pertaining to NACE publications.

Robert A. Lad Receives 1954 Junior Author Award

Robert A. Lad, head of Chemistry of Materials Section, Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics was selected to receive the National Association of Corrosion Engineers Junior Award for 1954. It was presented during the 1955 NACE 11th Annual Conference and Exhibition at the Palmer House in Chicago, March 7-11.

Selection was made because a paper by Dr. Lad and Dr. Sidney L. Simon, chief of Physics of Solids Branch, Lewis Flight Propulsion Laboratory, titled "A Study of Corrosion and Mass Transfer of Nickel by Molten Sodium Hydroxide" was judged to be the most meritorious of those published in CORROSION during 1954 by an author under 34 years of age.

Dr. Lad has a MS in physical chemistry and a PhD in inorganic chemistry from the University of Chicago. His experience includes research in boron hydride chemistry, gas adsorption, mass spectrometry and hydrocarbon combustion. For the past four years he has been working in solid state physics and on mechanism of mass transfer and corrosion in molten salts and hydroxides.

Recipients of the award are chosen by the NACE Junior Awards Committee of which Norman Hackerman, professor of chemistry, University of Texas is chairman.

Regional Management Committee Has New Head

H. C. Van Nouhuys, with Southeastern Pipe Line Co., Atlanta has been named chairman of the Regional Management Committee succeeding L. A. Baldwin, Johns-Manville Sales Corp., New York. Mr. Baldwin, who has served many years on the board and as chairman of this committee, had been prevailed upon in 1954 to hold the chairmanship another year.

VAN NOUHUYS

More than 50,000 copies of reprints of technical material published in Corrosion during 1954 have been made.

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- Firms seeking employees, regardless of NACE membership, may run an advertisement of the same specifications indefinitely.
- Advertisements to other specifications will be charged for at standard rates.

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9-year progress record with present employer covering laboratory evaluation, technical reporting, sales-service, to present position as manager of manufacturing plant. Above related to phosphate coatings and finishes primarily, however interest is prevention of corrosion in any field. Interested in position challenging ability and financially rewarding, or potentially so. CORROSION, Box 55-9.

Metallurgical Engineer—BS degree, age 32, family. Ten years diversified experience in material specification, metals finishing, heat treating, corrosion. Now employed. Seeking permanent position with progressive northern California organization. Excellent references. CORROSION, Box 55-10.

Chemical Engineer — Professional licensee for really responsible position. Six years staff consultant to maintenance, production, purchasing personnel on all phases materials of construction in multi-plant chemical company. Two years pilot plant supervision organic process development. CORROSION, Box 55-11.

President Wachter Summarizes Progress of Association During His Administration

By Aaron Wachter

It is customary at the annual business meeting of the association for your president to review major events and report on progress during his year of office. Also, at this meeting, reports of other officers and heads of staff committees give you more comprehensively and coherently the story of our progress within their departments. At the risk of some degree of repetition, I shall mention some items that they will cover more fully. In addition, I shall make some remarks bearing on our immediate and long range future.

I am happy to report that the National Association of Corrosion Engineers has continued to grow, to improve and to progress. Pride in our accomplishments can be taken by all of you, because credit for them goes to all levels of our organization. As long as we continue to work together toward fulfillment of the high aims of the NACE, our future is bright and our prospects for successful accomplishment are assured.

Gains in Membership

During this past year we have made substantial gains in membership. The net increase in 1954 was 423 so that our total membership in good standing as of January 1, 1955, was 4900. Although this increase may appear to be somewhat smaller than in previous years, actually, the number that joined our association was in the same magnitude as in previous years but was offset by resignations and dropping a substantial number of delinquent members. There is no indication, as yet, that we are approaching a limit in membership size.

In one very important membership category, namely, in corporate memberships, we have made disturbingly poor progress. The net gain in such members during the past year was only 8, giving us a total of 389 corporate members as of January 1, 1955. The previous year our net gain was 19 and the year before 24. So, you see, we are now just barely holding our own. This small net increase does not mean that only 8 companies joined as new corporate members. Actually, 35 new memberships were taken, but 27 corporate members resigned. This points up the dual character of our problem which is, not only to obtain additional corporate members, but also to retain those that we have.

You might wonder why this should be emphasized so strongly as a problem of the association. The answer is very simple. We need and, in fact, must have the financial support that such memberships bring to us. I shall enlarge somewhat on this a little later. In addition, it is a necessary manifestation of support from industry for our aims and activities. Since our objectives and activities are directed toward the benefit of industry, you would be inclined to think that it would be easy to convince companies to become corporate members. This is true, but experience has shown that the contact is most effective at the local, that is, the sectional level. Some local sections have acted vigorously in this regard and have obtained excellent results. Unfortunately, not enough of our local sections fully realize the importance and need for their activity in this direction.

Sections Increase

Growth of our association is shown further by the increase in number of sections during the year. On January 1, 1954, our 6 regions had a total of 37 sections. During 1954, 10 new sections were added, giving a total of 47 sections. More new sections are now being formed. This is gratifying progress of importance to our organization. Good distribution of strong, successful sections is bound to mean a strong, successful national organization.

Several regional conferences were held during the year. These regional conferences are useful and important in many respects. They provide additional and often convenient opportunity for the member to participate in the activities of the association. It is especially gratifying to note the increase in meetings of our technical committees at regional conferences. For example, 18 committee meetings were held during the conference of the South Central Region last fall. It is obvious that increased participation in technical committee activities will result from the opportunity to attend committee meetings in different parts of the country.

Financial Status Sound

Review of our financial status shows that our condition is sound, but that we are far from being wealthy. Expenditures continue to be scrutinized most carefully so that we are able to put aside a little each year as insurance against possible "rainy" days in the future. Our total expenditures for 1954 came to just about a quarter of a million dollars. The dues paid by active members contribute actually only a small part toward expenses of the association. The total costs of our services amount to about $51 per member. To a large degree we have to depend upon corporate memberships to support our activities and services. The annual dues for such memberships are $100 per year. Insufficient gains in corporate memberships in relation to increased active memberships has made it necessary to increase annual dues of active members from $7.50 to $10 starting this year. Your board of directors did this with great reluctance; they had no other choice.

Technical Committees Active

I am most happy to report outstanding progress of our technical committees. This is a major activity of the NACE which we confidently expect will be a most important source of strength to the association and of service to the membership. The new organization of our Technical Practices Committee has been in operation for a year. It gives every appearance of being a sound basis for future progress and development. We have now some 65 technical committees placed in 6 organizational groups and there is plenty of room for additional committees since we have an organizational structure to accommodate them. The membership in technical committees now totals about 830. Since mid-June of 1954, there were about 200 addi-

(Continued on Page 82)

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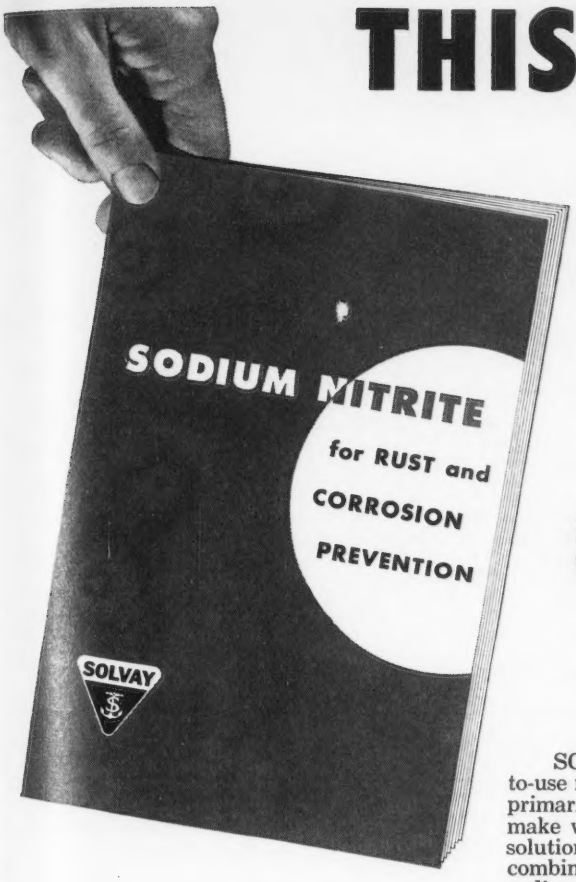

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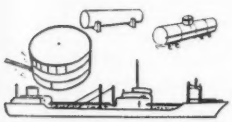
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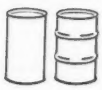
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President Wachter–

(Continued From Page 80)

tions to their rosters. Committee activities and output are increasing; for example, 10 committee reports were completed in 1954 and more are coming along. In no small part this satisfying progress has been aided by assignment of a member of our Central Office staff to full-time duty as secretary of our Technical Practices Committee. Among other things, he is responsible for the highly informative News Section on the Technical Committees which appears now in each issue of CORROSION.

This Conference and Exhibition in Chicago is our eleventh national meeting. It is the major annual event of the association. We have scheduled this week a program of important papers on a wide diversity of corrosion subjects. We have a fine exhibition of materials and services for prevention of corrosion. We have a large number of technical committee meetings scheduled. We have a multitude of opportunities for social, technical and business meetings for those attending from all parts of this country and Canada and even from far places overseas. I want to take this opportunity to express our very sincere appreciation for the hard work and splendid job done by the General Conference Committee, by Bill Ewing, Hal Bilhartz, Bob Rydell and John Anthony, and by each of their committee members.

At this point I wish to report to you the results of our letter ballot election for national officers and directors that was held in 1954. Frank L. Whitney, Jr. has been elected president; W. F. Fair, vice-president; Russell A. Brannon, treasurer; W. H. Stewart, director representing active members; R. R. Pierce and C. G. Munger, directors representing corporate members.

Their terms of office will commence on March 11, 1955, the last day of this annual convention.

In addition, owing to the resignation of J. Pat Casey as a director representing corporate members, the board of directors appointed P. H. Smith to fill the unexpired portion of Casey's term. Also, the election of Bill Fair as vice-president prior to completion of his term as director representing active members created a vacancy. The board of directors has appointed O. E. Murrey to fill this vacancy.

Finally, as your President for this past past year, I have been impressed by the load of work and responsibility this position entails. Largely because we are developing and progressing, the job is far from being automatic and routine. For this reson, it certainly has been stimulating. The energetic and conscientious work of my colleagues in NACE administration has been of inestimable help. In fact, the credit for our successes goes to them and to you, the members of NACE.

Tracy Takes Over As Editorial Review Chairman

A. W. Tracy, American Brass Company, took over the chairmanship of the NACE Editorial Review Subcommittee during the Eleventh Annual NACE Conference at Chicago in March. At the same time, J. W. Ryznar, 1954-55 chairman, retired from the committee. Dr. Ryznar had been a member and chairman of the committee for five years.

It was agreed that additional members are needed on the committee to handle the anticipated greater load of manuscripts. Mr. Tracy expects to be able to add three members to the committee.

Present for the meeting were J. W. Ryznar, National Aluminate Co., Chicago; A. W. Tracy, American Brass Company, Waterbury, Conn.; R. S. Treseder, Shell Development Co., Emeryville, Cal.; Irwin C. Dietze, City of Los Angeles; John W. Nee, Briner Paint Mfg. Co., Corpus Christi, Texas and J. J. Harwood, Office of Naval Research, Washington, D. C.

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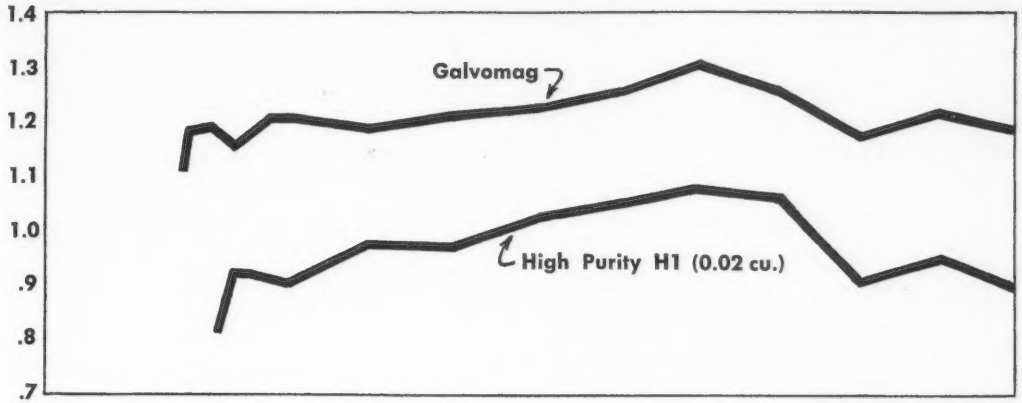

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Association Had Moderately Successful Financial Year, Treasurer Tells Members

By R. A. Brannon
Treasurer, NACE

NACE had a moderately successful year in finance matters during 1954. While some goals of membership and income as set up in the budget, were not reached, some expenses were less than budget provisions.

The number of members which NACE has is important to its treasury since membership dues are an important source of income. Figure 1 shows that growth in active membership has been quite satisfactory. Growth in the number of corporate members, who are so important because of the substantial financial support they provide through their annual dues of one hundred dollars each, was not as satisfactory. It is gratifying, however, that such a large number of companies and organizations recognize the value of NACE to them and continue their memberships.

Income from three principal sources, conference, regular business and publications is shown in Figure 2 for the years 1946 through 1954 with budget provisions for 1955. Income from each source during 1954 was less than budget provisions but the increase was in keeping with increases during previous years and corresponded closely with increase in membership. In preparing budget estimates of income for 1955 an attempt was made to be realistic rather than optimistic. The moderate increases which have been provided should not deter anyone from going all out to increase membership or to sell advertising and exhibit space. The substantial increase provided for dues from active members results from the increase in these dues from $7.50 to $10.

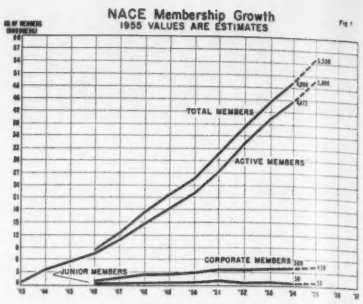
It may be seen from Figure 3 that most of the income was applied to providing services to members. This is as it should be in a non-profit organization. Based on the year end figure of 4900 members, NACE collected and disbursed about $50 for the benefit of each member.

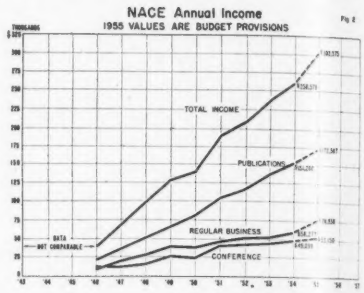
Any organization whether it is operated for profit or not, should have more income than expense. Since 1946 NACE has accomplished this through the efforts of many individuals who helped to increase income and of others who worked to provide as much service to members as practicable at costs within budget provisions. The cumulative excess of revenue over expenses is called Association Equity and was $122,122.97, on December 31, 1954. This equity is largely in the form of available funds invested in savings association shares all guaranteed by the Federal Deposit Insurance Corporation and in securities issued by the U. S. Treasury or guaranteed by an agency of the U. S. Government.

Table 1 shows NACE to be in good financial condition. Most assets could be converted into cash in a short time and the principal obligations, represented by amounts received in advance and revenue deferred, are that NACE continue its present activities.

Abstract Committee

At a meeting of the Abstract Subcommittee March 7 at the Palmer House, Chicago, the following were present: G. H. Cloud, Miss Ivy M. Parker, Norman Hackerman, R. D. Misch and Miss Agnes Humphrey.





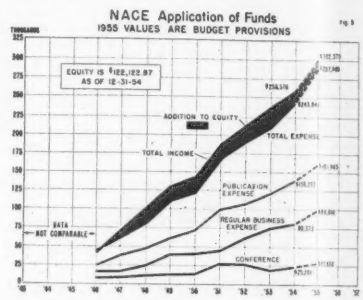


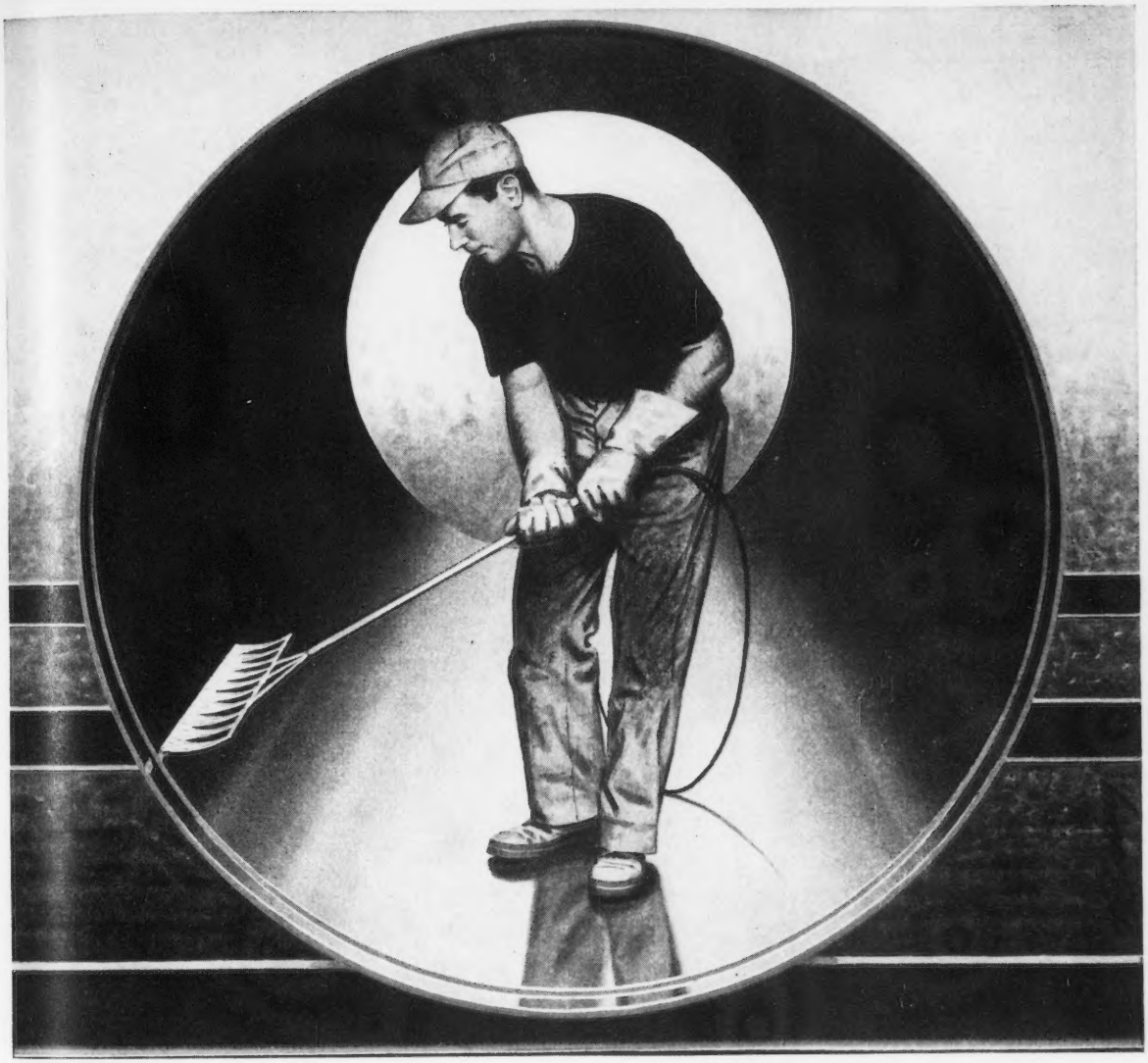
Table 1—Balance Sheets as of December 31, 1954 and December 31, 1953, Compared

ASSETS

	December 31, 1954	December 31, 1953	Increase (Decrease)
Current Assets			
Cash in Banks and on Hand	$ 32,045.05	$ 26,285.52	$ 5,759.53
Accounts Receivable			
Members—Corporate	600.00	800.00	(200.00)
Advertising	3,996.61	3,000.59	996.02
Reprints	241.84	784.85	(543.01)
Conference	375.00		375.00
Other	13.80	189.25	(175.45)
Investment in United States Government Securities	35,000.00	90,000.00	(55,000.00)
Inventories of Technical Literature and Abstract Cards	22,370.17	12,909.52	9,460.65
Interest and Dividends Receivable	718.93	406.78	312.15
Postage Deposit	377.22	216.79	160.43
Total Current Assets	$ 95,738.62	$134,593.30	($38,854.68)
Investments			
Shares in Savings Associations	$ 68,000.00	$	$68,000.00
Special Funds			
TP-IG Research Fund Cash in Bank	$ 4,098.56	$ 8,098.56	($ 4,000.00)
Educational Funds Cash in Banks	1,435.14	1,443.56	(8.42)
Total Special Funds	$ 5,533.70	$ 9,542.12	($ 4,008.42)
Fixed Assets—At Cost			
Office Furniture and Equipment	$ 14,927.73	14,108.29	$ 819.44
Less Reserve for Depreciation	7,379.72	5,912.74	1,466.98
Fixed Assets, Less Depreciation	$ 7,548.01	$ 8,195.55	($ 647.54)
Deferred Expenses			
Expenses incurred to December 31, 1954, Applicable to Conference of Subsequent Year	$ 3,702.27	$ 4,643.64	($ 941.37)
TOTAL ASSETS	$180,522.60	$156,974.61	$23,547.99

LIABILITIES AND ASSOCIATION EQUITY

	December 31, 1954	December 31, 1953	Increase (Decrease)
Current Liabilities			
Accounts Payable	$ 166.45	$ 472.28	($ 305.83)
Federal Old Age Benefit Taxes	133.04	109.66	23.38
Federal Income Tax Withheld from Payroll	1,100.28	1,108.80	(8.52)
Accrued Advertising Commissions	12.00	37.50	(25.50)
Total Current Liabilities	$ 1,411.77	$ 1,728.24	($ 316.47)
Amounts Received in Advance			
Dues of Active Members, Applicable to Subsequent Years	$ 15,786.25	$ 10,570.50	$5,215.75
Dues of Corporate Members, Applicable to Subsequent Years	8,600.00		8,600.00
Exhibitors' Space Rentals at 1955 and 1954 Conferences	7,145.50	9,053.00	(1,907.50)
Magazine Subscriptions	5,025.75	4,291.75	734.00
Total Amounts Received in Advance	$ 36,557.50	$ 23,915.25	$12,642.25
Revenue Deferred			
Dues—Corporate Members	$ 8,229.33	$ 8,870.88	($ 641.55)
Subscriptions to Magazine "Corrosion"	3,067.33	2,825.25	242.08
Advance Payments for Abstracts	3,600.00	2,600.00	1,000.00
Total Revenue Deferred	$ 14,896.66	$ 14,296.13	$ 600.53
Contributions for Research and Educational Purposes			
Research	$ 4,098.56	$ 8,098.56	($ 4,000.00)
Educational	1,435.14	1,443.56	(8.42)
Total Contributions for Research and Educational Purposes	$ 5,533.70	$ 9,542.12	($ 4,008.42)
Association Equity—Exhibit C	$122,122.97	$107,492.87	$14,630.10
TOTAL LIABILITIES AND ASSOCIATION EQUITY	$180,522.60	$156,974.61	$23,547.99



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Detecting "holidays" is the task of this electrical inspection apparatus. In the new 56-inch Bull Run water pipeline for Portland, Ore., less than one holiday for every 100′ of pipe was found — an almost perfect job.

The thorough inspection assures that any holiday is caught and corrected and that every inch of the pipeline is completely protected by Barrett pipeline coatings. Nine thousand gallons of Barrett waterworks primer, 2300 tons of Barrett waterworks enamel and 2,300,000 sq. ft. of Barrett tarred asbestos felt protect the Portland pipeline inside and out.

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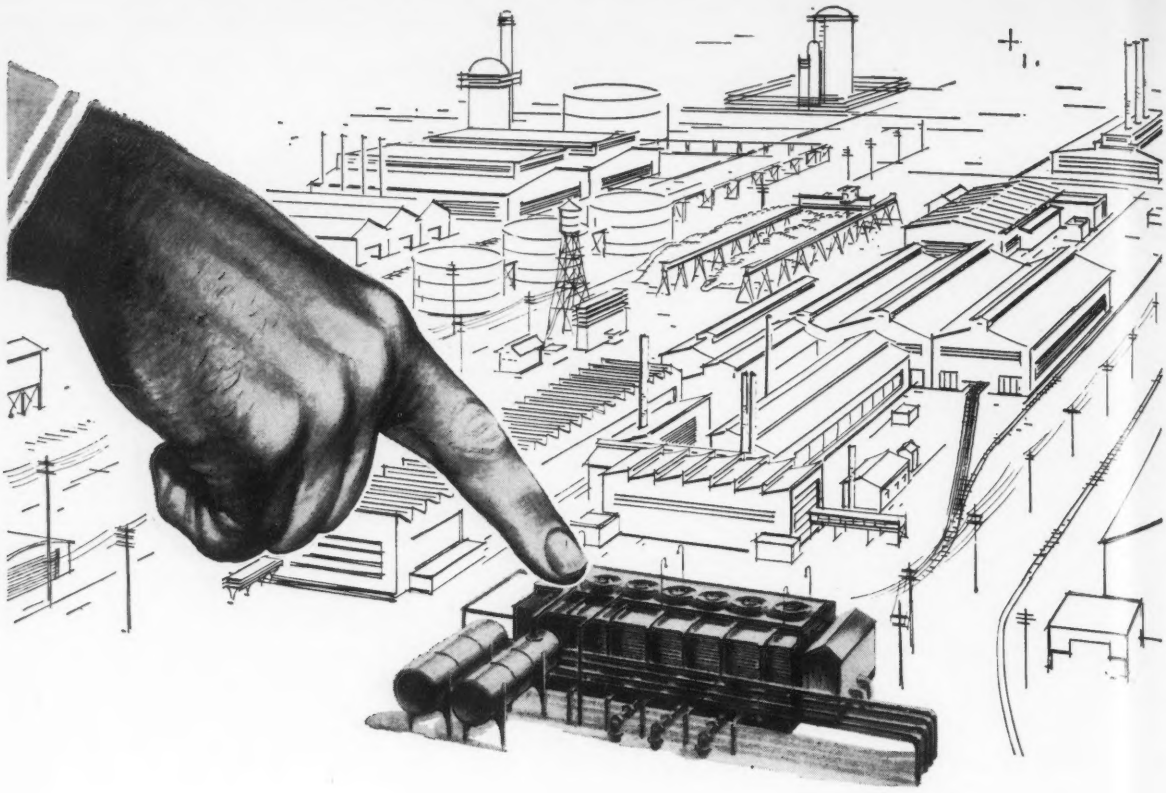

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Technical Committee News

High Temperature Sulfide Corrosion Group Formed

Corrosion by Hydrofluoric Acid to Be Probed By T-5A-6 Headed by T. L. Hoffman

Corrosion by hydrofluoric acid will be studied by a new task group formed under Unit Committee T-5A. T. L. Hoffman, Phillips Petroleum Company, Atomic Energy Division, Idaho Falls, Idaho, is the chairman of the new task group. The new group, designated T-5A-6, held its first meeting during the conference in Chicago.

Four areas of attack were proposed at the first meeting. Problems related to HF evolution from the manufacturer of phosphorus and phosphates will be studied under H. O. Teeple of the International Nickel Company. HF alkylation of hydrocarbons to high octane gas will be studied under H. H. Bennett, Socony-Vacuum Oil Company. Manufacturer of HF and storage and shipping of pure HF including safety devices will be studied under R. R. Pierce, Pennsylvania Salt Manufacturing Company. Aqueous solutions and chemical processes will be studied under N. D. Groves, General Electric Company. The task group will study other problems relating to corrosion by HF if interest is shown by T-5A members.

Committee on Offshore Structures Is Organized

A new committee to study Corrosion of Oil and Gas Well Producing Equipment in Offshore Installations was approved by T-1 at the committee's meeting in Chicago. D. F. Dial, Jr. of the Pure Oil Company, Houston, was appointed chairman of the new Unit Committee designated T-1M. A meeting of this new unit committee was held on February 10 in Houston, where twenty-five members attended.

The scope of the committee is as follows: This committee is interested in the specific problem of corrosion of equipment and installations used in offshore drilling and producing. It should endeavor to assemble and compile information on the various materials and techniques being used to control this corrosion. It should evaluate these materials and techniques and make such information available to all members concerned with this problem.

Larson Heads Domestic Water Analysis Committee

T. E. Larson, Illinois State Water Survey, is the newly elected chairman of Unit Committee T-4E, "Analysis of Domestic Waters." Mr. Larson plans to study the past work done by the committee with the consideration of changing the name of the committee and possibly broadening its scope.

W. F. Oxford Is Elected New Chairman of T-1

W. F. Oxford, Jr., Sun Oil Company, Beaumont, Texas has been appointed chairman of NACE Technical Group Committee T-1 on Corrosion in Oil and Gas Well Equipment. Mr. Oxford succeeds E. C. Greco, United Gas Corporation, Shreveport, La. who served as chairman of T-1 the past year.

Operating under T-1 are ten unit committees including a new committee authorized at the Chicago meeting. The unit committees are studying problems including condensate well corrosion, sweet oil well corrosion, sour oil well corrosion, metallurgy, sulfide stress corrosion cracking, oil string casing corrosion, oil field structural plastics, inhibitors for oil and gas wells and corrosion of offshore oil and gas well installation structures and equipment.

Three technical reports were completed by T-1 unit committees during 1954.

Pipe Coating Conductance Standard to Be Revised

Some revisions to the recently published report of T-2D on Standardization of Procedures for Measuring Pipe Coating Conductance were approved during the NACE 11th Annual Conference in Chicago. Appointment of a task group to carry out detailed revisions of the tentative standard before September, 1955 is under consideration.

Proposed revisions include a change in the definition of "leakage conductance," simplification of derivations in the appendix and general corrections of some equations.

W. E. Huddleston, Huddleston Engineering Co., Bartlesville, chairman, presided, with 33 present.

Specifications for Wrapping Materials to Be Prepared

Task groups have been organized to prepare specifications for glass wrap, rock shield, asbestos felt and rag felt pipe protection by T-2J on Pipe Wrapping Materials. The committee believes identification specifications will make it possible for the customer to know what he is using.

Clark A. Bailey, Johns-Manville Sales Corp., New York, chairman presided over the meeting attended by 40 persons. O. W. Wade, Transcontinental Gas Pipe Line Corp., Houston was elected vice-chairman.

Organization Meeting Set for Week of May 8 At St. Louis Hotel

Twenty-two members and guests attended the T-5B High Temperature Corrosion committee meeting held in Chicago during the conference. One of the most important actions during the meeting was the tentative organization of a task group to be formed to study sulfide corrosion at high temperatures.

M. E. Holmberg, consulting engineer of Houston, will act as temporary chairman of the task group. The organizational meeting of the task group will be held at the Jefferson Hotel in St. Louis the week of May 8, 1955. Anyone interested in becoming a member of this task group may reach Mr. Holmberg at 4101 San Jacinto Street, Houston 4, Texas.

125 Hear Paper on Sulfide Stress Corrosion Cracking

A paper titled "Effect of Martensite on Sulfide Stress Corrosion Cracking," by M. F. Bold and R. C. Bowden, National Tube Div., United States Steel Corp. was heard by members of T-1 on Corrosion of Oil and Gas Well Equipment during its March 7 all-day meeting at Chicago. There were 125 present.

The committee also heard a report on cathodic protection applied successfully to well casings and approved a report by T-1J on Oilfield Structural Plastics scheduled to be published soon in CORROSION.

Formation of a new committee, T-1M on Corrosion of Offshore Drilling and Production Equipment was approved. Chairman is D. F. Dial, Jr., The Pure Oil Co., Houston.

Fink Is Appointed to Head T-3 on General Corrosion

F. W. Fink, Battelle Memorial Institute, Columbus, Ohio has been appointed chairman of NACE Technical Group Committee T-3 on General Corrosion Problems. Mr. Fink served as vice-chairman of T-3 the past year and was appointed at the expiration of the 1954-1955 term of office held by F. M. Watkins, Sinclair Research Laboratories, Inc., Harvey, Illinois.

There are eight Technical Unit Committees under T-3 studying subjects including corrosion inhibitors, identification of corrosion products, annual losses due to corrosion, instruments for measuring corrosion, corrosion in the railroad industry, corrosion by high purity water, cathodic protection and tanker corrosion.

Unit Committees under T-3 completed two technical reports during 1954 and sponsored one complete symposium during the recent conference in Chicago.

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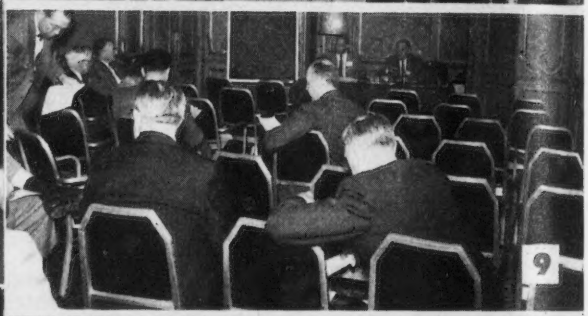
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TECHNICAL COMMITTEE MEETINGS during the Chicago Conference (photographs on left. Numbers refer to those in lower right hand corners of each photograph):

1. Meeting of Technical Committee T-1 on Corrosion in Oil and Gas Well Equipment. E. C. Greco, United Gas Corporation, Shreveport, Louisiana, Chairman, presiding.
2. L. P. Sudrabin, Electro Rust-Proofing Corporation, Newark, New Jersey, and R. M. Wainwright, University of Illinois, Urbana, Illinois, respectively chairman and vice-chairman at meeting of T-2C on Minimum Current Requirements.
3. Standing, P. E. Reynolds, Pacific Gas & Electric Company, San Francisco, California, vice-chairman, and seated, R. J. Schmidt, California Research Corporation, Richmond, California, chairman at T-2H meeting on Asphalt Type Pipe Coatings.
4. R. B. Bender, Plastic Engineering & Sales Company, Fort Worth, Texas, presiding at organizational meeting of new Unit Committee T-2K on Prefrabricated Plastic Film for Application to Pipe Lines.
5. Lyle R. Sheppard, Shell Pipe Line Corporation, Houston, Texas, chairman presiding at meeting of Task Group T-3D-1 on Electrical Holiday Inspection of Coatings.
6. Left, R. A. Bardwell, Chicago & Eastern Illinois Railroad, Danville, Illinois, chairman of T-3E on Railroads, and J. R. Spraul, General American Transportation Corp., East Chicago, Indiana, chairman of T-3E-1 on Corrosion of Railroad Tank Cars at meeting of T-3E-1.
7. T. P. May, International Nickel Company, New York, New York, chairman presiding at organizational meeting of new Unit Committee T-3G on General Cathodic Protection Problems.
8. J. Svetlik, Northern Indiana Public Service Co., Hammond, Indiana, chairman reporting on activities of T-4B-6 on Stray Current Electrolysis at meeting of T-4B on Corrosion of Cable Sheaths. Seated left, D. T. Rosselle, Southern Bell Tel. & Tel. Company, Atlanta, Georgia, vice-chairman of T-4B and seated right, Irwin C. Dietze, Dept. of Water and Power, Los Angeles, California, chairman of T-4B and vice-chairman of Group Committee T-4 on Corrosion in the Utilities Industry.
9. George E. Best, Mutual Chemical Company of America, Baltimore, Maryland, arising, upper left, to give a report at the meeting of T-4D on Corrosion by Deicing Salts. Seated at table, left, J. A. Temmerman, City of Rochester, Rochester, New York, vice-chairman of T-4D and right, M. B. Hart, Illinois Bell Telephone Co., Chicago, Illinois, chairman of T-4D.
10. A moment of relaxation during the meeting of Unit Committee T-5D on Plastic Materials of Construction.
11. Left, L. L. Sline, Sline Industrial Painters, Houston, Texas, chairman, presiding at meeting of T-6B on Protective Coatings for Resistance to Atmospheric Corrosion, and right, Howard C. Dick, Products Research Service, Inc., New Orleans, Louisiana, vice-chairman of T-6B.
12. Seated, R. H. Steiner, Atlas Mineral Products Company, Mertztown, Pennsylvania, chairman of T-6R on Protective Coatings Research, receiving some information from L. L. Whiteneck, Long Beach Harbor Dept., Long Beach, California, standing, vice-chairman of Group Committee T-6 on Protective Coatings.

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Authors of technical material published in Corrosion are indexed annually in December.

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Manuscripts on corrosion subjects are accepted without invitation for review prior to publication in Corrosion.

7 PLS PLANTS
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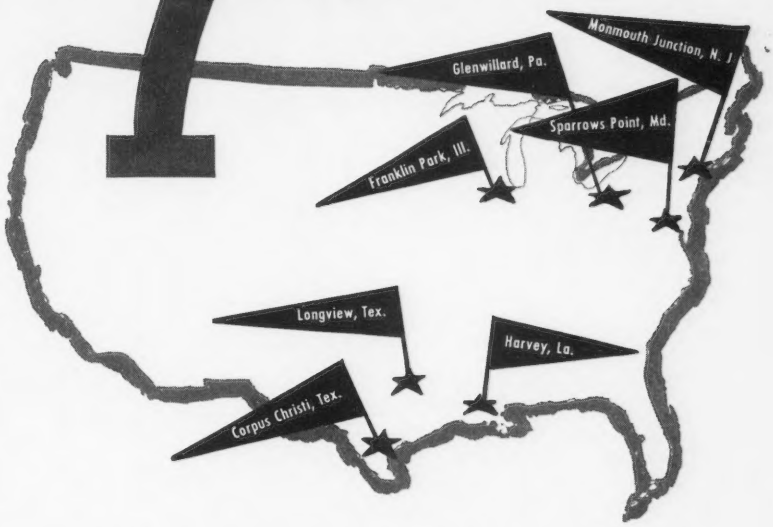

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Improvements in Inhibitor Feeding Scanned by 44

Specific questions on Corrosion in Sour Oil Wells was the subject of the meeting of T-1D held in Chicago. Forty-four members and guests attended and J. A. Caldwell, Humble Oil & Refining Company, chairman, presided.

Questions discussed during the meeting included: 1) Is it necessary to wash an inhibitor down the tubing casing annulus with well fluids? Can field data be found to support the answer? 2) Should an inhibitor be injected daily, semi-weekly, weekly, or at even longer intervals?

The current project of the committee is to incorporate answers obtained at this meeting into a new report which will present advances in corrosion prevention practices since the T-1D report on sour oil well corrosion published in 1952.

Parts of Report on Bonding And Grounding Reviewed

Parts of a T-4B-6 report entitled "Summary of General Practices as Pertaining to Bonding and Grounding of Cable Sheaths for Corrosion Mitigation" were discussed by 96 members and guests of T-4B at the committee's meeting in Chicago. The report will be circulated to committee members for additional comments and approval for subsequent publication.

Also discussed was a summary of questionnaires on "Stray Current Electrolysis." This summary will be completed and submitted to members of the committee for approval in the near future.

150 Attend Meetings of Cathodic Protection Group

Reports on polarization of graphitized cast iron and the location of reference electrodes were heard by 150 persons at a meeting of T-2C on Minimum Current Requirements for Cathodic Protection at Chicago. A task group has been formed to compile tentative minimum current requirements for cathodic protection before an October, 1955 meeting.

L. P. Sudrabin, Electro Rust-Proofing Corp., Belleville, N. J., chairman, presided.

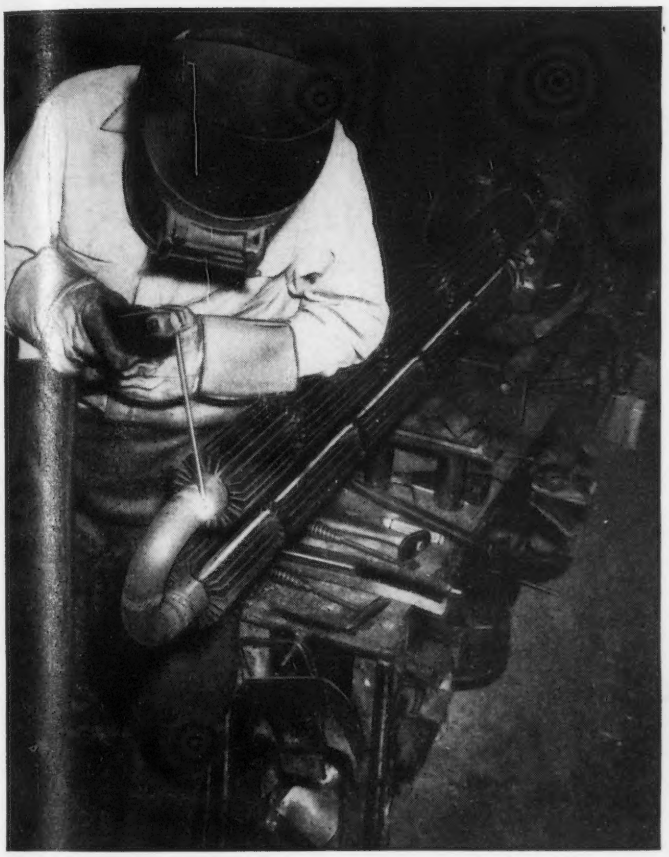
Task Group Is Named to Survey Ribbon Anode Data

J. N. Hunter, Jr., Service Pipe Line Co., Tulsa has been named to head a new task group of T-2A on Galvanic Anodes. The group will gather performance data on ribbon anodes. T-2A also is considering as a new project collection of data on the performance of the new high potential magnesium anodes in fresh and salt water. Performance of packages anodes also is being studied.

A new chairman will be elected by letter ballot.

H. A. Robinson, The Dow Chemical Co., Midland, Mich. chairman, presided over the meeting attended by 35.

Corrosion can be controlled



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A HASTELLOY alloy C safety valve similar to the one being lapped here was inspected recently after handling 500 "pop" reliefs of scalding acid vapors. It was found that the alloy surface still had its original polished finish.

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HUMBLE

Ashbaugh Heads Process Industries Group T-5

W. G. Ashbaugh, Carbide & Carbon Chemicals Co., Texas City, Texas is the new chairman of NACE Technical Group Committee T-5 on Corrosion Problems in the Process Industries. Mr. Ashbaugh succeeds Paul J. Gegner, Columbia-Southern Chemical Corp., Barberton, Ohio.

Four unit committees and fourteen task groups are active under T-5 studying problems including sulfuric acid, acetic acid, chlorine, nitric acid, high temperature corrosion, corrosion by cooling waters and plastic materials of construction.

Heads of T-4 Divisions Hold Luncheon Get-Together

Chairmen of subdivisions of T-4 on Utilities exchanged views and got acquainted at a luncheon March 10 during the NACE Eleventh Annual Conference at Chicago. Present were R. M. Wainwright, University of Illinois, Urbana, chairman of T-4A; I. C. Dietze, Dept. of Water and Power, Los Angeles, chairman of T-4B; D. T. Rosseile, Southern Bell Telephone and Telegraph Co., Atlanta, Ga., vice-chairman of T-4B; M. B. Hart, Illinois Bell Telephone Co., Chicago, chairman of T-4D; V. V. Kendall, National Tube Div., U. S. Steel Corp., chairman T-4E; R. R. Ashline, City of Los Angeles, chairman of T-4F and F. E. Kuhlman, Consolidated Edison Co. of N. Y., chairman of T-4.

Reports on Rubber, PVC, Epoxies Are Given

Tentative reports on chlorinated rubber, PVC, and Expoxies were presented to Unit Committee T-6A at the committee's meeting in Chicago. R. McFarland, Jr., Hills-McCanna Company, presided at the meeting, attended by fifty members and guests.

The tentative reports will be circulated to manufacturers for review and will be revised then to incorporate suggestions by manufacturers for review by committee members. It is the aim of the committee to publish these three reports by the end of 1955.

Reports on Performance of Anodes; Rectifiers Readied

A report giving comparisons of performance of carbon, graphite and steel anodes will be submitted for publication soon by T-2B on Anodes for Impressed Currents. Joint T-2B and National Electrical Manufacturers' Association committee also has tentatively completed material specifications for rectifiers.

T. J. Maitland, American Telephone and Telegraph Co., New York City has been elected new chairman of T-2B.

•

A tabular topic and alphabetical subject index to the material published in Corrosion's Technical Section is published annually in the December issue.

•

Authors of technical material published in Corrosion are indexed annually in December.

CORROSION CONTROL
PROTECTS INDUSTRY
NATIONAL ASSOCIATION OF CORROSION ENGINEERS
ORGAN A.D. 1945

General News

Numerous Corrosion Sessions Scheduled by AGA

Liquid Metal A-Power Plant to Be Evaluated

An engineering evaluation of a nuclear power plant system using liquid metal as fuel and designated Liquid Metal Fuel Reactor is being performed at the Atomic Energy Commission's Brookhaven National Laboratory. Developed at Brookhaven, the system is intended to generate electric power, "breed" fuel for itself and deliver by-products to waste tanks, all in continuous processes. Babcock and Wilcox Co., New York City, organized and is in charge of the study.

AEC has authorized construction of six reactors as part of its five-year nuclear power plan. Construction has begun on the pressurized water reactor near Pittsburgh and contracts have been let for the sodium-graphite reactor being designed by North American Aviation Co. in California. Oak Ridge National Laboratory in Tennessee and Argonne National Laboratory near Chicago each will be responsible for two reactors in the plan, all to be completed in 1960.

Oil Spreading Rate Seen As Key to Tenacity

Use of spreading rate of oil on metal to predict difficulty of removal is announced by American Electroplaters' Society. AES sponsored laboratory work on metal cleaning revealed evidence of relationship between ease of oil removal and spreading rate. Further work at Columbia University is scheduled on this subject.

Knowledge of composition of oil used for lubrication, cutting aid or rust protection is not required to tell how hard it will be to clean a metal because users now can test oil by watching how fast a drop spreads over clean sample of metal, AES states. The society points out that test is of value beyond metal cleaning field as data obtained may help develop more tenacious rust preventives, stronger filmed motor lubricants and more durable waxes. It said study will be extended to cover greases and similar material.

Research Started Into Minimum Paint Film Data

Determination of minimum paint film thickness for economical protection of hot rolled steel against corrosion is first phase of a major corrosion research program being sponsored by the Federation of Paint and Varnish Production Clubs. Project has been assigned to North Dakota Agricultural College at Fargo with Wouter Bosch, head of the college's Paint Technology Laboratory as coordinator.

Rapid Abrasion Resistance Measurement Explained

A rapid method for measuring abrasion resistance of organic coatings on metals that determines, under controlled operating conditions, time required for high-speed jet of fine abrasive particles to abrade substrate has been developed by the National Bureau of Standards.

Method is similar in principle to procedures where loose particles fall, rub or are blown against test specimen, but does not depend upon abrading area of definite size and uses continuously fresh supply of abrasive particles. Carbon dioxide gas under controlled pressure propels abrasive powder from vibrating storage chamber through nozzle to impinge at high speed upon test specimen. Solenoid valve operated with manual switch turns flow of powder on or off and mounting arrangement for test specimen and nozzle assembly permits rotational adjustment while angle between nozzle and surface to be abraded is adjusted by graduated rotating disk attached to nozzle shaft. Specially calibrated taper gage permits rapid, accurate adjustment of nozzle-to-specimen distance at abrading angles from 20 to 90 degrees.

Spent particles and coating debris are removed through vacuum exhaust outlet at one end of test chamber. Rapid monitoring of abrasive flow rate is accomplished by weighing tube having rubber diaphragm with hole to accommodate nozzle tip at one end and diaphragm of ordinary filter paper at other end to permit gas escape while trapping particles.

Operating conditions can be varied to accommodate extreme differences but it is usually desirable to use a nozzle-coating distance of 0.04 inch, gas pressure of 40 lb/in,^{2} flow rate of approximately 0.15 grams per second and abrading angles of 90 or 45 degrees. The 90 degree angle simulates leading-edge type erosion encountered by aircraft in flight and 45 degree angle simulates scuffing wear which aircraft receives during maintenance.

Abrasion time for given material depends on test conditions, increasing almost linearly with increasing nozzle-to-coating distance, decreasing with increasing pressure and angle of abrasion (from 90 to about 30 degrees) and rising again at smaller abrading angles.

End point of method is first show of bare metal, readily detected when coating and substrate differ in color as is usually the case, otherwise inspection with hand lens may be used. Studies of bureau show method distinguishes significantly between materials difficult to differentiate by qualitative means although degree of correlation with actual service performance has not yet been established definitely.

Anodes, Instruments, Paints, Other Topics Will Be Discussed

The American Gas Association's 1955 Distribution, Motor Vehicles and Corrosion Conference is scheduled at the Netherland Plaza Hotel in Cincinnati, April 12-15.

Corrosion Mitigation Practices in Distribution Systems are to be discussed during the corrosion portion of the Wednesday noon luncheon conference.

Airless Paint Spray (speaker not announced) and Re-Evaluation of Undercoating by W. H. Head, Public Service Co. of New Hampshire, Manchester, are included in the Automotive and Mobile Equipment Session to be held Thursday morning.

A Corrosion Session also to be held Thursday morning includes discussions on: Surface Methods of Attaching Anodes to Pipelines by S. C. Jones, The Cincinnati Gas and Electric Co. Economics of a Paint Survey, by J. G. Geoghegan, Consolidated Edison Co. of N. Y. Inc., New York City. Surface Potential Measurements by O. W. Wade, Transcontinental Gas Pipe Line Corp. Houston and Causes of Ferrous Pipe Corrosion by F. E. Kulman, Consolidated Edison Co. of N. Y., Inc.

An introduction to corrosion by N. P. Peifer, The Manufacturers Light & Heat Co. Pittsburgh and a symposium and demonstration of instruments including a panel to answer questions on various instruments is planned for Thursday afternoon.

A discussion on Construction and Maintenance including a corrosion mitigation panel is to be held during the Automotive and Mobile Equipment Session Friday morning and a Report of Subcommittee on Plastic Pipe Standards and a Report of the Society of the Plastics Industry's Pipe Activities are to be presented Friday afternoon.

Rubbish Burning Eyed As Contributor to Smog

A complete engineering study of sanitary landfill for rubbish as aid in battle against smog in Los Angeles has been recommended to the Los Angeles County Board of Supervisors by the Air Pollution Foundation. That backyard burning of rubbish contributes an estimated 500 tons of airborne materials to air pollution in the Los Angeles Basin was pointed out by the foundation which recommended backyard incinerators be replaced by efficient collection systems with final disposal made to local landfills when available or distant landfills when necessary.

•

Back issues of Corrosion for 1954 and for many issues of prior years are available.

NEW PRODUCTS – Materials – Service – Literature

Coatings for protection of floors against heavy traffic and corrosive spillage are manufactured by Dennis Chemical Co., 2701 Papin St., St. Louis 3. Designated as Perma-Skin Epoxy Coatings, they are based on use of catalysts to provide in an air-dry system properties previously obtainable only with high-temperature baking, the company says. Manufacturer claims coatings have excellent adhesion, abrasion resistance, toughness, flexibility, acid and alkali and solvent resistance. Company also produces Denflex Plastisol Metal Coatings used with a one-coat primer said to tightly bond plastisols to metal surfaces such as steel, copper, brass, aluminum or galvanized iron. Primer called Denflex No. 2386 may be applied by brushing, dipping, roller coating or spraying. Coatings are resistant to weathering, abrasion and corrosion and for electrical insulation, the company says.

•

Gears are made of a pre-alloyed steel powder made by water disintegration of molten metal by Hydreco Division of The New York Air Brake Co., marketers of product. Vanadium-Alloys Steel Co. developed the 4650 steel powder and fabrication into gears said to have tensile strength exceeding 100,000 psi and C-30 particle hardness was accomplished by Keystone Carbon Co. Hydreco claims tests prove gears are equal if not superior to cut gears originally used and have uniformity of one gear to another, superior surface finish on teeth, resistance to wear and high strength.

•

Bakelite Epoxy resins and Fiberglas cloth as laminate for patching sheet metal is said to effect savings up to 70 percent on auto-body repair costs according to report by Bakelite Co., a Division of Union Carbide and Carbon Co., 260 Madison Ave., New York 16. Arndt-Palmer Laboratories, Melvindale, Mich. packages the laminate.

•

Tenite Polyethylene, a molding and extrusion plastic is produced by Eastman Chemical Products, Inc., a subsidiary of Eastman Kodak Co. under licensing arrangement with Imperial Chemical Industries, Ltd. Manufacturer claims spherical pellets have advantages of uniform flow from hopper into heating cylinder of molding or extrusion machine reducing chance of bridging-over, will not readily catch or hold dust and foreign particles, have low bulk factor and fewer fines make cleaning hopper or molding or extrusion machine easier when changing colors.

•

The American Brass Co., 25 Broadway, New York 4 has scheduled construction of brass mill in the Paramount district of Los Angeles. Mill is to produce copper and copper-base alloys in form of sheet, strip, rod, tubing and drawn copper products and will have estimated annual capacity of about 30 million pounds.

•

College of Engineering, Ohio State University has scheduled the second Annual Conference for Engineers at the university on May 6. A general session and departmental technical meeting will be held to bring participants up-to-date on outstanding engineering problems and developments. Registration is at 9 a.m. in the university's Union Hall on the campus.

•

Valve and Flange covers made from synthetic fabric called Dynel and said to be acid and caustic resistant are produced by the Textile Fibers Department of Carbide and Carbon Chemicals Co., a Division of Union Carbide and Carbon Corp., 30 E. 42nd St., New York 17. Designated as ChemKovers, product has proven by test to be superior in initial cost and upkeep to heavy-metal covers as well as in ease of installation and storage, the company says.

•

Two "Scotch" Brand polyester pressure-sensitive film tapes said to possess unusual strength although 2 mils thick are produced by Minnesota Mining and Manufacturing Co., St. Paul. Designated No. 850 and 852, tapes are metalized and differ in that No. 852 is printable and has special polyethylene-coated paper

(Continued on Page 95)

OIL WELL CASING PROTECTED FROM EXTERNAL CORROSION

Magnesium anodes are now being used effectively to stop external corrosion on oil and gas well casing. Here's how one major oil company used this low-cost method on 130 wells, 5000 feet deep:

CSI engineers, who helped develop the method, provided a complete turn-key job. They first surveyed the wells, using special surface instruments,* to determine the current density required for cathodic protection. Then they installed DOW magnesium anodes using CSI equipment and trained personnel. The installation was designed for a 10 year life.

CSI offers expert consultation and installation services, as well as a complete line of brand-name cathodic protection materials—for both anode and rectifier jobs.

Call or write for competitive cost estimates or quotations. Ask about the new Dow "Galvomag" which gives 20 to 35 per cent more current output than other anodes of similar size.

* *Pat. Applied For.*

CSI

CORROSION SERVICES INCORPORATED

Tulsa, Oklahoma

P. O. Box 7343, Dept. C Telephone: Tulsa 4-0082

NEW PRODUCTS

(Continued From Page 94)

liner. Manufacturer claims products resist acids, alkalies, ketones, hydrocarbons, esters and other common solvents and will not crack, chip or peel. Outdoor weathering tests in various sections of nation over nearly 2-year period showed no appearance change, the company says. Properties include 25 pounds tensile strength and 40 ounces of adhesion per inch of tape width and 100 percent elongation. Company recommends tapes for uses such as protecting fuel cells from rivet abrasion in aircraft and splicing rolls of paper, plastics and textiles in manufacturing and treating processes.

•

Wrought Iron for Highway Construction is title of eight-page booklet published by A. M. Byers Co., Pittsburgh to assist highway officials and engineers in selecting materials for use in corrosive highway surfaces. Discussion of how wrought iron resists corrosion and fatigue and technical bulletins on wrought iron and its applications are included. Booklet is available from Advertising Department of the company.

•

A Plastic-Coated storage battery designed for emergency lighting is produced by Exide Industrial Division of The Electric Storage Battery Co., Box 8109, Philadelphia. Designated 3-COE-7 Tytex, battery has polystyrene container and cover which company claims has extremely high impact resistance and mechanical strength in addition to chemical and physical stability. Plastic also is impervious to electrolyte, is light in weight and easy to keep clean, the company says. Short circuits are prevented by triple insulation with inert plastic and rubber which give maximum discharge characteristics because of low resistance and battery requires addition of water once or twice a year under normal operation, the company reveals.

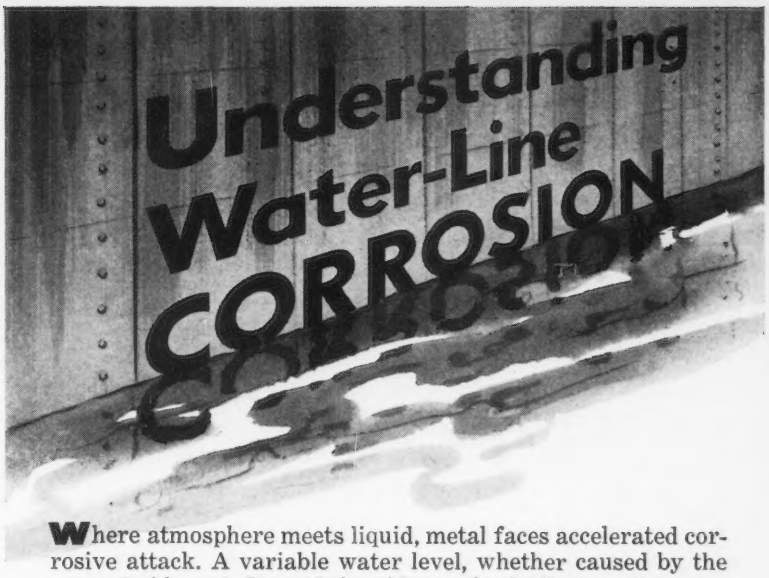
•

Technique of Molding refractory plastics such as polyvinylchloride is announced by Stokes Molded Products Division of The Electric Storage Battery Co., Box 8109, Philadelphia. Manufacturer claims economical processing of pure nonplasticized polyvinylchloride in intricate and complex moldings for large production runs and small lots is permitted. Adulteration of rigid PVC molding compounds with fillers and plasticizers, thus lowering plastic's natural chemical resistance and mechanical strength is solved by process, the company says.

•

A Hot-Spray-Applied vinyl-based protective coating called Tygon ATD, said to be extremely dense and impermeable with complete absence of pin holes is produced by The U. S. Stoneware Co., Akron. Product combines vinyl and other plastic resins to form high solids content viscous material that reverts to liquid form on heat application avoiding use of excessive amounts of solvents to achieve spraying consistency, the company says. Manufacturer claims productis resistant to most commercial acids and alkalies as well as alcohols, water and oils but is attacked by aro-

(Continued on Page 96)



Where atmosphere meets liquid, metal faces accelerated corrosive attack. A variable water level, whether caused by the normal ebb and flow of the tide or the buffeting of waves, or controlled within a vessel, becomes one of several forces that may combine to destroy metal.

Undulating or fluctuating motion brings to the surface unsaturated liquid which rapidly absorbs oxygen. Such motion also thins the liquid film on a metal surface, permitting dissolved oxygen to diffuse more rapidly and speed corrosive action.

Even where motion is not a factor and a constant water level is maintained, corrosion may attack most severely at the water line or immediately below. Again, a higher concentration of free oxygen at or near the surface may be a determinant, with convection currents carrying unsaturated liquid upward as oxygen-spent liquid bearing corrosion products tends to flow downward. A difference in electro-chemical potential between metal at the interface and meniscus and that just below, it is further believed, establishes the former as cathodic and the latter as anodic, thus intensifying near-surface deterioration of metal.

As in many another struggle, success in forestalling corrosive attack stems from accurate intelligence of the aggressor's plans and tactics. Adequate defenses can be erected only after correct evaluation of all of corrosion's forces and the ways in which they may combine in a specific action. A pioneer in the field of industrial metal protection, The Dampney Company is ready to apply to your corrosion-control needs the considered engineering judgement that derives from thorough technical knowledge and long practical experience in dealing with the vagaries of corrosion.

Let us know your service requirements — (a Dampney Coating Selector for recording pertinent data is available on request) — and a Dampney recommendation will be yours without obligation . . . right for you because individually job-selected to meet your specified needs.

MAINTENANCE FOR METAL

THE DAMPNEY COMPANY

HYDE PARK, BOSTON 36, MASSACHUSETTS

RODINE® 203
ACIDIZING INHIBITOR

provides positive protection for well tubing and acid storage equipment at high or low temperatures.

"Rodine" 203 is an organic inhibitor designed especially for acidizing.

It is neither destroyed nor precipitated by hydrogen sulfide. It does not stimulate localized pitting. It is readily soluble in water or acid.

Economical, effective, and easy to use, "Rodine" 203 provides maximum protection at minimum cost.

ACP CHEMICALS PROCESSES — *Write for Descriptive Folder* — ACP CHEMICALS PROCESSES

AMERICAN CHEMICAL PAINT CO.
AMBLER, PA.
Detroit, Mich. Niles, Calif. Windsor, Ont.

NEW PRODUCTS

(Continued From Page 95)

matic hydrocarbons, ketones and esters and that field tests indicate labor costs are cut as much as 20 percent.

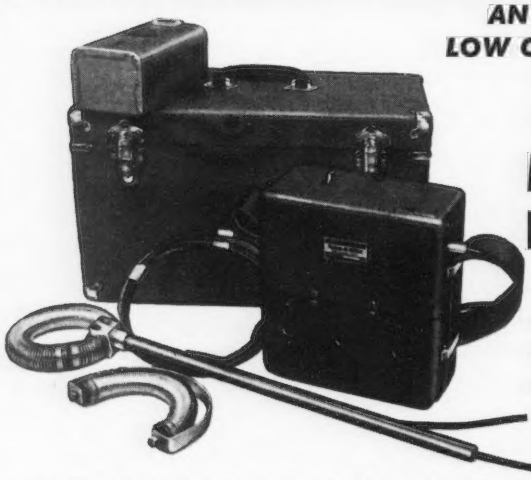
•

Chempro "Wedge-Lock" external mechanical seals are produced by Chemical and Power Products, Inc., New York City. Seals are designed for complete interchangeability with stuffing-box packing in pumps, agitators, autoclaves and other rotating processing equipment, the company says. They are recommended for use on equipment handling acids, caustics, solvents and other chemical liquids and slurries under wide range of operating conditions. Use of seal reduces hazards in handling corrosive, toxic, explosive and flammable liquids and eliminates shaft scoring, the company states.

•

Dihydroxy Diphenyl Sulfone is described in Technical Bulletin No. 0-118 which has been prepared by Organic Chemicals Division of Monsanto Chemical Co., St. Louis 4. Primary use of product is as bath addition agent in electroplating field. It may be used as intermediate in organic synthesis, particularly when phenolic compound stable to oxidizing action of light and air would be valuable, the company says. Several important DDS reactions and a bibliography are included in the four-page bulletin available from the company on request.

Here's The "Jeep" You Asked For!



AN ENTIRELY NEW LOW COST ALL-PURPOSE DETECTOR

Tinker & Rasor

MODEL E-4 DETECTOR

- **Lightweight**
- **D. C. Output**
- **Shock Proof Case**
- **Adjustable Voltage**
- **Non-Destructible Type Material**

The Model E-4 Detector is a portable instrument designed for all-purpose work and is adaptable to both large and small pipe. It features direct current, high potential output, accurate bell signal alarm, and is adaptable to both the full circle and half circle electrodes. It is adjustable from 2500 to 20,000 volts D. C. and offers a shock proof, non-destructible type case.

Write today for prices and complete detailed information.

TINKER & RASOR 203 Del Mar Place (P. O. Box 281) San Gabriel, California

PERSONALS

Albert P. Gagnebin has been appointed assistant manager of the Nickel Sales Department; **Edward B. Bitzer** as assistant manager of the Nickel Alloys Department and **Keith D. Millis** in charge of the Ductile Iron Section, Development and Research Division of the International Nickel Co., Inc., 67 Wall St., New York 5.

•

David Hendrickson has joined the engineering staff of the Hinchman Corporation, Engineers, Detroit.

•

Frank M. Cashin has been named a vice president of Kaiser Aluminum & Chemical Corp., 1924 Broadway, Oakland 12.

•

John S. Gerrard, formerly with Kuwait Oil Co. is now senior corrosion engineer with Messrs. Metal and Pipeline Endurance Ltd. His address is 41 Merton Rd., Prestwich, Manchester, England.

•

R. P. Ganchan has been named assistant general manager of Automotive Rubber Co., Inc.

•

E. M. Steinmann has been appointed Southeast sales engineer of the Atlanta Office, Royston Laboratories, Inc. Blawnox (Pittsburgh) Pa.

•

Philip H. Smith has been elected vice-president-sales engineer of the Nooter Corp., St. Louis.

•

Yale W. Titterington has been named general manager and Hugh Brady as vice-president and chief engineer of Corrosion Services, Inc., P. O. Box 7343, Tulsa.

•

Ben Carroll has been appointed research director of Furane Plastics, Inc., Los Angeles.

•

Douglas C. Lynch, formerly executive vice president of Brush Electronics Co. Cleveland, has been named president of the company.

•

Roger E. Risley has been named director of engineering and Fred T. Newell chief product engineer of Dresser Manufacturing Division, Bradford, Pa.

•

James L. Neal, Dallas sales manager for Owens-Corning Fiberglas Corp. Toledo 1, has been named Southern regional sales manager for the company.

•

E. W. Volkmann has been appointed manager of the Research Department of Koppers Co. Inc. Pittsburgh 19. Dr. Volkmann will be responsible for coordination of all Koppers research including work at its Verona, Pa. Research Center and elsewhere in the country.

•

Stephen D. Moxley has been named to succeed Charles Otto Hodges as president of The American Cast Iron Co., Birmingham, Ala. **Frank H. Coupland** has been appointed vice president and works manager, **Arnold J. Herrmann,** vice president and sales manager and **Kenneth R. Daniel,** vice president and chief engineer for the company.

•

Lowell H. Miller has been appointed an industrial sales representative for the Nubian Industrial Division of The Glidden Co. Cleveland.

Corrosion Abstracts

CORROSION CONTROL — PROTECTIVE INDUSTRIES — NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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1. GENERAL

1.1 Miscellaneous

1.1, 6.3.6

Examination of an Old Bronze Ship Spike Taken from a Wreck at Nags Head, N. C. C. L. BULOW. *Corrosion,* **10,** No. 7, 205 (1954) July.

Comparisons of microstructure of a bronze spike taken from a wrecked ship at Nags Point, N. C. with that of spikes from the frigate Constitution and nails taken from Boston's Old South Church roof fastening copper sheets dated 1838 establishes the age of the craft as the last half of the eighteenth or first half of the nineteenth century. 7930

1.2 Importance

1.2.2

What Corrosion Costs Canada. H. G. SMITH. *Can. Chem. Processing,* **37,** No. 10, 10 (1953) September.

The total annual cost of corrosion to Canada is conservatively estimated at 300 million dollars, as compared with nearly 5½ billion dollars to the U. S. A. Items contributing to Canada's annual corrosion bill include over $122 million for paint and lacquer coatings, including labor; over $5 million for galvanized sheet, wire, and pipe; nearly $5½ million for tinplate; $4¼ million for lead coatings and terne plate; $30,000 for nickel coatings; nearly $10 million for copper and copper alloys; $1 million for stainless steel; $22½ million for domestic hot water tank replacements (estimated at 10%); and over $112 million for repairs of internal combustion engines (60 percent estimated corrosive wear).

Not included in these figures are labor costs for miscellaneous coating applications, repairs, underground pipeline maintenance and the like; costs of cadmium and phosphate coatings and of boiler-water treatment; losses incurred by shutdowns, by material spoilage in corroded containers and by reduced efficiency, etc.—PDA. 7893

1.6 Books

1.6, 3.1, 5.1

Proceedings of the Short Course in Corrosion Held at the University of California. 119 pages, 1953. Dept. Conferences and Special Activities, University Extension, University of California, Berkeley 4, Calif.

A collection of papers presented at the University of California Short Course on Corrosion at Berkeley, February 2-6, 1953. Included in the book are discussions on fundamentals of corrosion, stress corrosion, corrosion of ferrous and non-ferrous metals, various coatings, corrosion in the process industry and in public water systems, cathodic protection principles and practices, corrosion study and testing including use of radiotracer techniques and high temperature corrosion. 8032

1.6, 5.3.4, 6.5, 5.4.5, 5.9.1

Surface Protection Against Wear and Corrosion. Book, 1954, 461 pp. American Society for Metals, Cleveland, Ohio.

Lectures given to members of the ASM at the National Metal Congress, 1953. Includes: Testing for Wear Resistance and Selecting Materials for Wear Resistance, both by H. S. Avery; Electroplated Coatings and Anodized Coatings, both by J. M. Hosdowich; Case Hardening of Steel by Carburizing, Case Hardening of Steel by Carbonitriding and Cyaniding, Case Hardening of Steel by Nitriding, and Diffusion Treatments for Wear Protection, all by M. B. Bever and C. F. Floe; Metallizing by H. Vanderpool; Selective Heat Treatment by S. L. Case and H. J. Grover; Hard Facing, Hard Facing Alloys, Tungsten Carbide Hard Facing, Chromium Carbide Hard Facing, Martensitic Irons, Cobalt-Base Alloys, Nickel-Base Alloys, Martensitic and Pearlitic Steels, Austenitic Stainless Steels and Austenitic Manganese Steels, all by H. S. Avery; Hard Facing for Hot Wear Resistance by T. Gaynor; Economic Justification of Protective Coatings by C. C. Harvey; Surface Preparation and Pretreatment of Metals Prior to Painting by A. J. Liebman; Organic Coatings for Normal Services by A. J. Eickhoff; Corrosion Prevention by Paint Maintenance in Severe Industrial Atmospheres by K. Tator; Specifications for the Painting of Metals by J. Bigos; Cathodic Protection and Galvanizing by H. A. Robinson; Metallizing by H. S. Ingham; Electrodeposited Coatings by F. Ogburn. In some cases short bibliographies are provided but a few of the lectures in the corrosion group are too brief to be really helpful.—BNF. 8018

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NACE will NOT accept orders for photoprint or microfilm copies of material not published by the association.

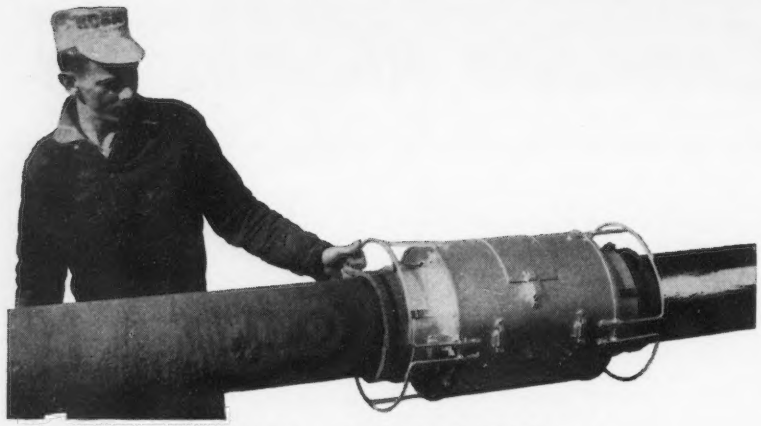
2. TESTING

2.2 On Location Tests

2.2.2, 6.2.1

Report of Committee A-5 on Corrosion of Iron and Steel. A. P. JAHN, chairman. American Society for Testing Materials, Preprint No. 3, 1953, 33 pp.

Presents work of the committee on atmospheric exposure tests and tests for weight of Zu coatings. Tables, phototographs.—BTR. 7914



EITHER WAY...

ROSKOTE PAYS

Whether applied by Roskoter* (top), brush (bottom) or spray, Roskote *cold-applied* mastic's drying speed and handling ease cut manhours from work schedules. Yet it costs only three cents per square foot of coverage.

Roskote dries to the touch in 20 minutes and is ready for backfill in an hour. It bonds readily to previous coatings of coal tar or asphalt and is *non-toxic.*

This tough, natural resin-base mastic sets to a flexible film without brittleness or sag through a temperature range of —40°F to 375°F . . . withstands the pressure, strain and abrasion of the meanest soils. Roskote alone has an electrical resistivity of 20 megohms per sq. ft. and is highly resistant to the corrosive attack of acids, alkalies, salts and moisture.

Find out for yourself why over 100 major utilities and pipeline companies specify Roskote for their "tough" jobs. Write for complete technical information and free sample, and while you're at it ask about application by Roskoter, Royston's revolutionary new coating device.

*Patent Applied For

ROYSTON
LABORATORIES, INC.
BOX 112-C, BLAWNOX
PITTSBURGH 38, PA.

District Offices
P. O. Box 1084
N. Decatur Station
Atlanta, Georgia

•

P. O. Box 1754
Tulsa, Oklahoma

ROSKOTE

50a

2.3 Laboratory Methods and Tests

2.3.2, 2.4.2

Three Accelerated Corrosion Tests for Materials and Finishes. SAM TOUR. *Materials and Methods,* **38,** No. 5, 110-113 (1953) Nov.

The use of simulated service tests for measuring corrosion-resistance is briefly discussed. An alternate condensation tester is described and illustrated. The apparatus consists essentially of a number of chambers through which the samples to be tested are rotated, mounted on a turntable. The chambers are provided with controlled humidities or controlled gas atmospheres. In a typical test cycle, the samples are subjected to alternate condensation and evaporation 15 times/hr. The Tour wear-corrosion tester is described and its use for evaluating the wear-resistance of successive layers of electroplate such as palladium/rhodium/platinum on nickel brass, gold/nickel on brass and rhodium/nickel on brass and steel is illustrated. An aerated sea-water testing apparatus is also described and illustrated.—MA. 7983

2.3.2, 2.4.2, 8.8.1

Corrosion Testing for Your Plant. M. F. MUELLER AND A. D. LAEHDER. *Chem. Eng.,* **60,** No. 10, 193-195 (1953) October.

Test apparatus suitable for most laboratory corrosion test work is described. The unit 1) permits determination of the proper materials of construction in cases involving process liquors for which no applicable published corrosion data are available; 2) allows for a positive selection of the most economical material of construction; 3) indicates the contaminating characteristics of materials of construction on the purity of chemicals manufactured; 4) materially reduces the number of instances where materials of construction must be selected wholly on the basis of literature references; 5) establishes a firm basis of comparison for use in tabulating and correlating corrosion test results. The equipment and general test procedure are described and the test results evaluated. 7997

2.3.2, 6.2.2

Corrosive Action of Highly Concentrated Nitric Acid on Iron. (In German). ERICH FITZER, HANS HOHN, AND JOHANN SEKAL. *Werkstoffe u. Korrosion,* **4,** No. 8-9, 290-298 (1953) Aug.-Sept.

Influence of test conditions, pre-test treatment and composition on intergranular attack is described. Photographs, graphs, tables. 10 references.—BTR. 8026

2.3.2, 6.2.5

Factors Affecting the Testing of Stainless Steels in Boiling Concentrated Nitric Acid. J. E. TRUMAN. *J. Applied Chem.,* **4,** No. 5, 273-283 (1954) May.

Corrosion rate obtained when testing stainless steel in concentrated boiling nitric acid is affected by method of testing. Main source of error is contamination of test acid by dissolved steel. If corrosion products accumulate, acceleration of attack occurs and volume of acid has a serious effect on corrosion rate. Chromium dissolved in acid affects corrosion rate only if it is in the sexivalent state and degree of acceleration is proportional to the amount of chromium

in this condition. Chromium can be oxidized from Cr^{3+} to Cr^{6+} with nitric acid but several factors, including type of condenser used and strength of test acid, affect the reaction. Cyclic tests, in which the acid is changed at intervals, are not the answer to errors introduced by this process since mechanism of attack in Cr^{3+}-bearing nitric acid leaves the stainless steel in a condition susceptible to heavier attack even in pure nitric acid and this leads to earlier serious contamination of acid used in later cycles. Less satisfactory materials may be selected for testing procedure since steels most resistant to pure nitric acid are not necessarily most resistant to nitric acid contaminated with Cr^{3+}. Tests were performed on 18/13/1 chromium/nickel/niobium steel. Graphs, tables, 4 ref.—INCO. 7951

2.3.5, 2.3.7

Electrical Measurements at High Temperatures as an Efficient Tool for Thermal Analysis. F. W. GLASER AND D. MOSKOWITZ. *Powder Met. Bull.*, **6**, No. 6, 178-185 (1953) Dec.

Describes apparatus for measuring the high temperature resistivity of bar samples, with results obtained for hot pressed rods of nickel, molybdenum, steel, TiB_2, titanium carbide, Mo_2B_5 and $TiSi_2$. Melting points and transformations could be observed.—BNF. 7922

2.4 Instrumentation

2.4.3

Conductivity Now a Useful Nondestructive Testing Tool. HENRY N. STAATS. *Materials & Methods*, **38**, 124-126 (1953) October.

Describes instrument, developed in Germany, which directly measures electrical conductivity of materials. It can be used for sorting nonferrous metals and alloys, identifying unknown metals, evaluating hardness and checking heat treating results. Photographs, charts.—BTR 7906

2.4.3, 2.3.9, 7.2, 7.5.4

Ultrasonic Testing of Steel Rolls and Steel Cylinders. H. J. SEEMAN AND W. BENTZ. *Arch. Eisenhuttenw.*, **24**, No. 1-2, 47-52 (1953).

Mode of operation of Scam ultrasonic testing device, developed in France and used in authors' study. Inspection of rolling mill, etc. rolls of cast and forged (chromium-molybdenum) steel for macrodefects, such as pipe and comparative structure studies, using ultrasonics, principally the pulse reflection method. Usefulness of ultrasonic testing for control of structures obtained by heat treating. Possibilities of testing cylinders used for storage of highly compressed gases by a combination through-transmission and reflection method. Detection of defects such as laminations in cylinder walls by the same combination method. Inspection of cylinders completely and partially filled with liquids in vertical as against horizontal position. Condensed translation available. Henry Brutcher, P. O. Box 157, Altadena, California. 7885

2.4.3, 7.1

Practical Experiences Gained in the Ultrasonic Inspection of Turbo Generator Rotor Forgings as Acceptance Test. (In German). R. SCHINN. *Metall*, 7, No. 13-14, 502-506 (1953) July.

Report on acceptance testing of large turbo generator rotors by the pulse-reflection test method. Location of reflecting zones and deductions concerning their nature. Usefulness of ratio of defect deflection to terminal echo for measuring the magnitude of defects whose orientation is known; conditions to be met in this connection. Importance of proper acoustic coupling. Testing procedure proposed. Correct evaluation of test results on rotors for dependable estimates of the nature of the defects. Information obtained by supplementary mechanical tests on trepanned cores, confirming the ultrasonic test results. Consideration of the particular severe conditions of the rotor in order to avoid unjustified rejects based on ultrasonic test data. Translation available: Henry Brutcher, P. O. Box 157, Altadena, California. 7881

3. CHARACTERISTIC CORROSION PHENOMENA

3.2 Forms

3.2.2, 3.5.8

Slip Lines, Etchpits and Corrosion Pits. A. H. ABDOU. *Phil. Mag.*, **45**, No. 360, 105 (1954) January.

Single crystals of high purity zinc were electrolytically polished in 20 percent chromic acid and deformed in tension. The crystals were then either left exposed to the atmosphere or etched in 20 percent chromic acid for various periods. In the first case, corrosion pits developed rapidly along slip lines and at random on the surface. In the case of etching, however, etchpits grouped themselves along slip lines only, leaving the

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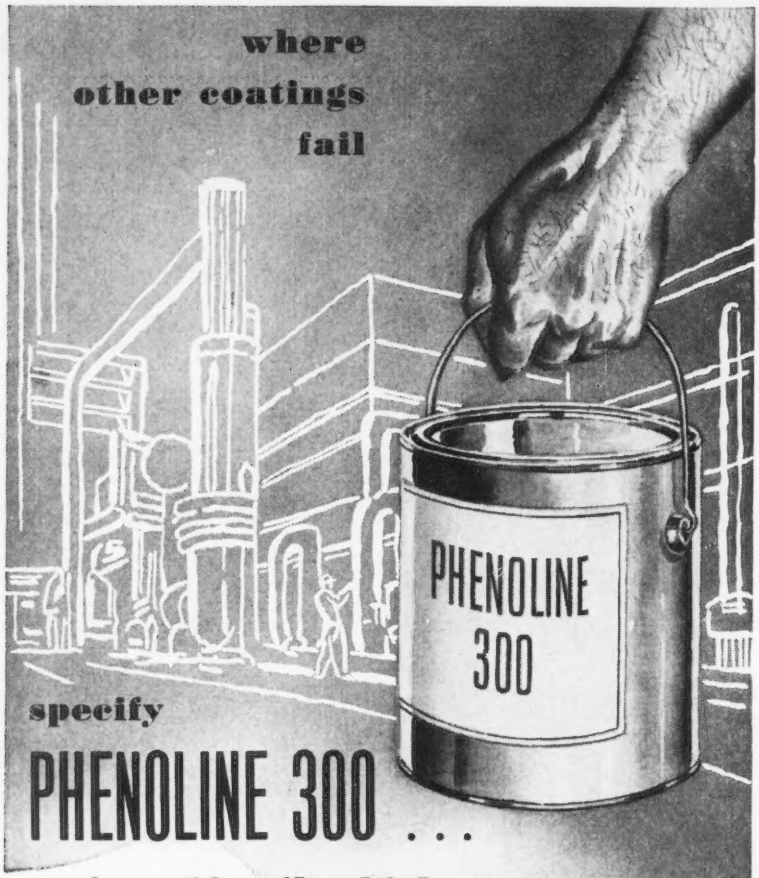

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rest of the surface free. With prolonged etching, existing etchpits in slip lines deepened and new ones developed at random.—ZDA. 7982

3.2.2, 3.8.4

Further Studies of the Mechanism By Which Hydrogen Enters Metals During Chemical and Electrochemical Processing. L. D. McGraw, W. E. Ditmars, C. A. Snavely and C. L. Faust. Battelle Memorial Inst. Natl. Advisory Comm. Aeronaut., Tech. Note No. 3164, 37 pp., March 1954.

Investigation was a continuation of efforts to develop fundamental concepts which would be useful in preventing or alleviating hydrogen damage to steel. NACA Tech. Note No. 2696 presented a new mechanism which postulates that the entry of hydrogen into metals from chemical and electrochemical action occurs when hydrogen-metal alloy formation is simultaneous with discharge (or release) of hydrogen atoms. In the present work the phenomena relating to hydrogen entry into steel were studied further. In general, the results support the newly postulated concepts. Appendices include one dealing with experiments on the effect of hydrogen content on bend angle for steel specimens. Illustrations, tables, 17 references.—INCO. 7962

5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2.1

Coordination of Corrosion Control. Hugh L. Hamilton. *Pipe Line News*, **25**, 44, 46, 48 (1953) Dec.

Outlines steps necessary for adequate coordination of corrosion control measures.

Similar article: There's Trouble Ahead if Utilities Fail to Coordinate Their Corrosion Control Measures. Hugh L. Hamilton. *Gas*, **29**, 51-52 (1953) Dec. 7934

5.2.1, 8.9.5

Cathodic Protection as Applied to Royal Canadian Naval Vessels in Active Service. K. N. Barnard. *Chemistry & Industry*, No. 7, 172-182 (1954) Feb. 13.

Techniques of application; results obtained and advantages and disadvantages of systems employing magnesium, steel, graphite or platinum anodes. Diagrams, graphs, table.—BTR. 7996

5.2.2, 7.7

Cathodic Protection for Steel Mill Grounding Systems. J. F. Headlee. *Iron Steel Engr.*, **31**, No. 111, 113-115 (1954) March.

A description of the design and installation of the grounding systems at Fairless Works, U.S. Steel Corporation is given as a typical case of cathodic protection of grounding systems. The many factors involved in the design of an adequate grounding system include the types of soil, size and number of electrodes and depth of penetration into earth. The ground bed plan is shown and illustrates the layout used for steel ground rods and magnesium anodes. Steel rods were 40 ft. long x ¼-inch diameter. The anodes were 10 ft. long, 4 x 4 inches square magnesium cast on the center of a 20 ft. long, 1 inch diameter steel rod. The rods and anodes were spaced ten to twelve feet from each other which is found to give optimum resistance per minimum number of electrodes. The rods were all con-

nected in parallel by 250-MCM neoprene jacketed copper cable which was terminated at the test plate. Likewise the anodes were all connected in parallel and terminated at the test plate. The test plate facilitates separation of the two elements for checking resistivity and current voltage characteristics and permit separation of equipment ground cables for measuring insulation to ground. Building structure ground cables were also terminated on test plates. This method of cathodic protection also afforded cathodic protection for building substructures within the environment of the anodes. —ALL. 7955

5.2.3, 8.9.5

Cathodic Protection in Shell Depot Ship. *Marine Eng.*, **76,** 434 (1953) Oct.

The "Shell Quest" outfitted as a depot ship for under water exploration has the under water portion of the hull cathodically protected by four groups of graphite anodes suspended over the side and supplied with current from two special motor generators in the engine room which convert the ship's 220-volt current to low voltage supply controllable over a wide range. Under normal conditions one motor generator can protect the hull with as little as 2 kw. 7940

5.2.4, 2.3.5

Cathodic Protection Meters for Field Personnel. JAMES R. COWLES. *Petroleum Engr.*, 26, D-79, D-82 (1954) May.

Discusses use of zinc bar as permanent reference electrode, with special meter for field checking of cathodic protection. Procedure is applicable to well-coated lines. Two instruments are described. Use of this method enables field personnel to catch failures in system and is an aid to engineer in trouble shooting. 7956

5.4 Non-Metallic Coatings and Paints

5.4.2

Investigation to Develop Heat Resisting Coatings to Protect Metal Alloys Against Corrosion: Quarterly Progress Report For the Period Ending March 31, 1953). National Bureau of Standards, Quarterly Progress Report No. 2, NBS-4C-102, April 1, 1953, 14 pp.

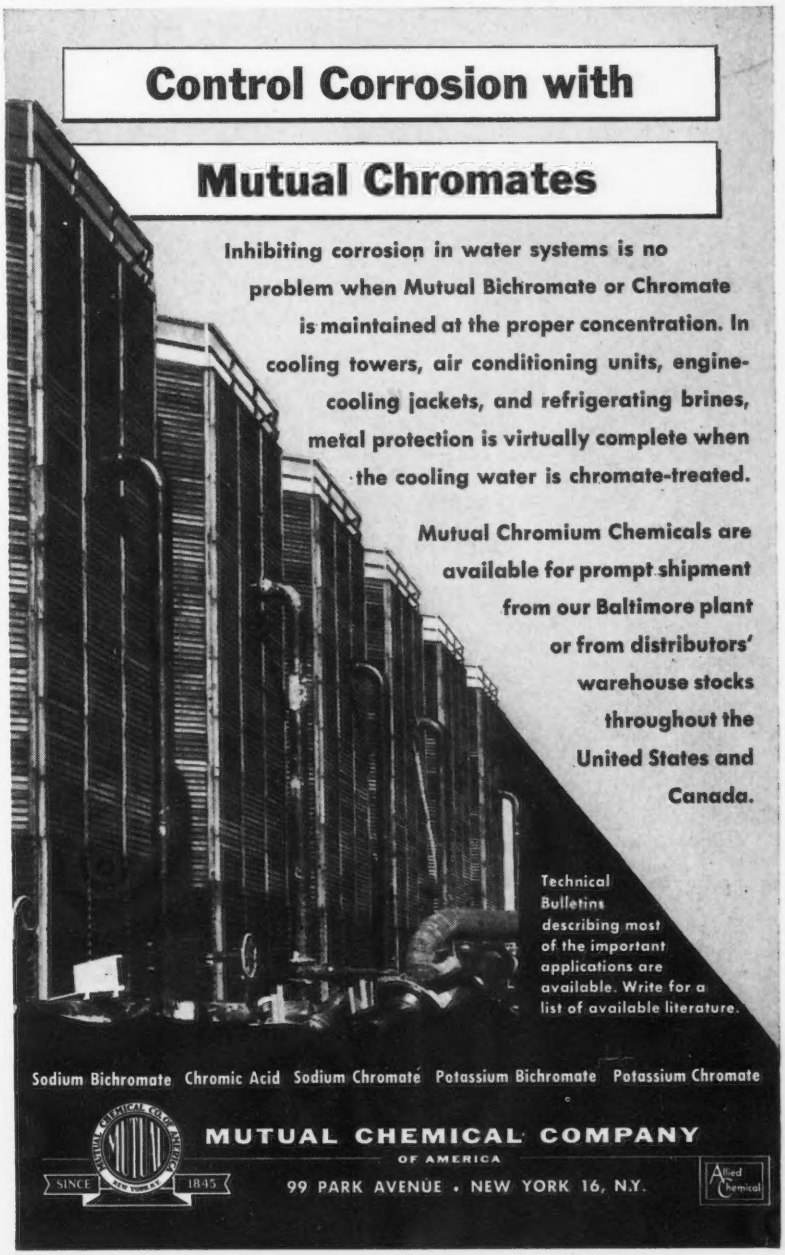
During the quarter, a total of 36 additional coatings were designed, compounded and tested. The ceramic-metal coating did not bond to the base metal during firing and flaked off before testing. Two unfritted coatings showed good adherence to the base metal after firing but did not afford appreciable protection against oxidation in the extended heating test. Several of the frit-refractory coatings adhered well to Inconel and Types 321, 309 and 310 stainless steel. None of the coatings gave complete protection to Type 321 stainless steel at 1900F. Two coatings appeared to protect Inconel at this temperature and several coatings when applied to Types 309 and 310 stainless steel were in good condition after the extended heating test. —NSA. 7917

5.4.2

A Designer's Guide to Vitreous Coatings. I. Service Properties. II. Metal Selection, Processing, and Design. ROBERT L. STEDFIELD. *Machine Design*, **25,** Nos. 1 & 2, 141-149, 166-176 (1953).

Part I. Stedfeld lists the important properties of vitreous coatings as being: 1) resistance to acids, alkalies, chemicals and corrosion; 2) suitability for high temperatures and for protection against high-temperature oxidation; 3) resistance to abrasion and wear; and 4) the possible appearance value of porcelain enamel. Information is given on optical properties of enamels, their acid- and corrosion-resistance and their thermal and mechanical properties. Tests for the service properties of porcelain enamels are given in a table and graphs present data on the relative resistance of porcelain enamels to the corrosive action of hot water, the effect of extended heating on the strength of coated and uncoated stainless steel, the abrasion-resistance of standard enamels, the effect of metal thickness on the impact strength of 0.013-in. thick porcelain-enamel coatings and the impact strength as a function of thickness of an enamel coating.

Part II. Under the heading Metal Selection, Stedfeld discusses the qualities required in the ferrous alloys employed for enamelling. For ceramic coating it becomes possible to use some non-ferrous alloys, particularly those in the stainless and heat-resisting groups. A number of aluminum alloys can be enamelled. Descriptions are given of wet- and dry-process enamelling and information is presented on sheet-metal design technique for porcelain enamelling. Special points to be observed in design include accessibility for enamelling, sharp edges and radii, high-temperature effects, correct metal thickness and coating strength. consideration has to be given to the after-effects of stamping, forming and drawing, as the enamelling process can relieve internal stresses and cause warping or distortion. The welding of enamelled articles is discussed with information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given on methods for preventing hair-lining. An account of assembly methods for coated products stresses the importance of methods of preventing chipping.—MA. 7907

5.4.2, 1.4

Enamel Bibliography and Abstracts. ROGER L. FELLOWS, compiler. Book, 487 pp., 1953. American Ceramic Society, 2525 N. High Street, Columbus 2, Ohio.

Presents a compilation of all published material from 1940 to 1949. Includes abstracts on porcelain enameling and references pertaining to refractory coatings for metals.—BTR. 8047

5.4.5

Paint Faults and Remedies. Part I. H. C. BRYSON. *Corrosion Prevention & Control;* **1**; Nos. 2 & 4; 83-88, 104; 215-219 (1954) April, June.

Protection afforded to structural materials by coating them with paints of various types is one of best and most widely used methods of controlling corrosion. Paint faults, including lack of adhesion, adulteration, alligatoring, faulty application, bacterial growth, brittleness, blackening, blistering, blooming, bubbling and bleeding are briefly covered. Illustrations.—INCO. 8008

5.4.5

Corrosive Attack by Acidic Decomposition Products Evolved by Paints While Drying: A Technical Note. A. L. GLASS AND D. L. DORFMAN. *Corrosion,* **9**, No. 10, 344 (1953) Oct.

Corrosion on cadmium-, magnesium- and zinc-plated steels used to construct and pack helicopter blades was traced to decomposition products from the aluminum paint used.—RPI. 7924

5.4.8

Plastics Equipment Reference Sheet. Chlorinated Rubber Coatings. RAYMOND B. SEYMOUR AND ROBERT H. STEINER. *Chem. Eng. Progress,* **49**, 452 (1953) Aug.

Tabulates corrosion resistance of chlorinated rubber coatings.—BTR. 7968

5.8 Inhibitors and Passivators

5.8.2, 7.1

Protection Against Rust and Corrosion. *Automotive Ind.,* **111**, No. 4, 87 (1954) August 15; *Product Eng.,* 25, No. 8, 216 (1954) August.

Quicker yet longer rust prevention is said to be provided by a crystalline amine nitrite compound, a white powder about as fine as talcum which will not clog a flocking gun and can easily be applied with a squeeze bottle, a salt shaker or any similar device. Where spraying or dusting of the VPI-250 is impractical, the powder may be dissolved in alcohol and applied in solution. Powder has been effective in preventing corrosion under high humidity in aircraft and other internal combustion engines. Developed by Shell Oil Co.—INCO. 8014

5.8.2, 4.6.2

Hydrazine: New Aid to Water Treatment. ERIC R. WOODWARD. Mathieson Chemical Corp. *Power,* **97**, No. 11, 91-93, 212, 214, 216, 218 (1953) November.

British, American and German experiences on the use of hydrazine as a de-

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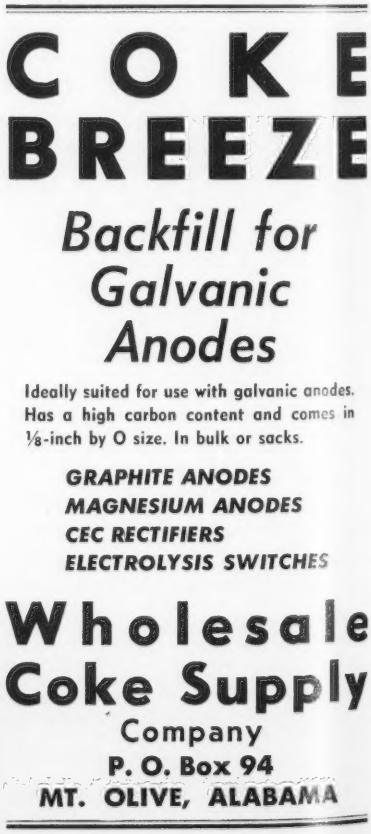
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oxygenating agent for boiler feedwater are summarized. Among hydrazine compounds successfully used as corrosion inhibitors in the USA, hydrazine hydrate is suitable for high-pressure boilers up to 1400 psig and dihydrazine sulfate for low-pressure industrial plant boilers. Dihydrazine phosphate is used in England to treat idle boilers.

Trial runs with hydrazine in England showed that the compound primarily scavenges free oxygen, with decomposition into water and nitrogen and that further hydrazine then reduces metal oxides (rust). Neither reaction changes the salt content of the feed water. In the absence of oxygen and oxides, however, catalytic or thermal decomposition takes place with the formation of nitrogen and ammonia, which is undesirable. Hence, excessive hydrazine dosages must be avoided.

Supplementary German experiences indicate that the amounts required for corrosion protection are much smaller for hydrazine than for sulfite. Moreover, in high-pressure plants with condensate feed, addition of hydrazine raises the pH, thus eliminating separate addition of alkali and subsequent neutralization.—PDA. 7904

5.8.2, 6.5.4

Borax Solutions Found to Inhibit Rusting. F. W. Blaisdell. U. S. Dept. Agriculture. *Civil Eng.*, **24**, No. 8, 65-66 (1954) August.

Use of small quantities of borax in a recirculating water system eliminated rusting. Series of tests was conducted to determine the effect of various concentrations of borax on corrosion and on the kinematic viscosity of water. Tests were made using steel coupons cut from hot rolled steel strip. Recirculating system to which the results were to be applied is made up of hot rolled steel shapes, plates and pipes. It is concluded that borax serves as an excellent rust inhibitor for steel and zinc and that, in the amounts required to inhibit rust, its effect on the specific gravity, surface tension and kinematic viscosity of water can be safely neglected in ordinary hydraulic laboratory work. Graphs.—INCO. 8033

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.2, 3.6.8, 3.8.2

Electrolytic Reduction of Iron Rust. A. S. Afanas'ev. *Zhur. Priklad. Khim.* **26**, 170-177 (1953); *Chem. Abs.*, **48**, Nc 6, 3165a (1954).

The electrical potentials of iron electrodes exposed to periodic wetting drying and sulfur dioxide were measured in an 8% potassium hydroxide solution. Surface changes and hydrogen evolution in the cavities of the rust due to cathodic polarization was observed microscopically. The most important depolarizing reactions were:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-;$$
$$Fe^{3+} + e^- \rightarrow Fe^{2+};$$
$$Fe^{2+} + 2e^- \rightarrow Fe;$$
$$H_3O + e^- \rightarrow H + H_2O.$$

Rusted iron is an effective oxygen cathode in the first stages of the electrolytic process by virtue of oxygen absorption. —EL. 8036

6.2.3, 3.7.3, 5.3.2

Resistance Welding of Coated Mild-Steel Sheet. A. J. Hipperson. *Sheet Metal Inds.*, 31, No. 323, 211-218 (1954) March.

Resistance welding is often used to join mild-steel components which have been previously coated or plated. Petrol tanks, fire extinguishers, food and chemical containers and radio chassis are typical examples. Presence of coatings, such as nickel, on mild-steel introduces various welding problems which are discussed and recommendations are made as to how best results can be obtained. Tables, graphs and 5 references.—INCO. 8030

6.2.4, 3.7.1

Line-Broadening of Martensite in Nickel Steels. R. A. Smith. *J. Iron Steel Inst.*, **173**, Pt. 2, 147-152 (1953) Feb.

X-ray diffraction-line shapes obtained from quenched medium- and low-carbon 3% nickel steels were recorded in a Geiger counter spectrometer. Fourier analysis was used to determine the true physical broadening from the observed line shapes of the martensite and of annealed iron which is assumed to exhibit experimental broadening only. The results indicate that the effects produced by martensitic transformation are similar to those obtained in cold-worked metals. Earlier work is substantiated in that the major part of the line-broadening is due to internal stresses, but the results indicate the presence of a particle-size effect. The carbon content is effective in determining the degree of internal strain remaining after transformation. Illustrations, 14 references.—INCO. 7889

6.2.5, 2.3.2, 8.1.2

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18-8 Stainless Steel Constructions. H. TOGANO. *Corrosion Engineering* (Japan), **3**, No. 2, 3438 (1954) April.

Because test specimens generally cannot be cut from construction, the author worked out a way to evaluate the susceptibility of 18-8 stainless steel constructions by disclosing characteristic metallographic structure on the constructions themselves with the following method. Holding the special electrolytic bath made of polyvinyl chloride pipe on any place of the constructions, electrolytic polishing and electrolytic etching were performed. Reagent used was 70% nitric acid for electrolytic polishing and 10% chromic acid for electrolytic etching. The metallographic structure disclosed was replicated to a small celluloid plate by "Sump" method and the replica was observed with miscroscope for the degree of chromium carbide precipitation.—JSPS. 8027

6.2.5, 3.2.3, 3.2.2

An Investigation of Intergranular Oxidation in Stainless Steel. Quarterly Progress Report No. 3. C. A. SIEBERT, M. J. SINNOTT AND R. E. KEITH. Engineering Research Inst., Univ. of Michigan. U. S. Atomic Energy Comm., NP-4934, Quarterly Progress Report No. 3, September, 1953, 39 pp.

The determination of the effect of temperature between 1600 and 2000 F on intergranular oxidation or corrosion in stainless steel and an examination of the effects of alloy composition are reported. Determination of the nature of the penetrating material in areas of intergranular attack and methods of reducing or elminating intergranular penetration were studied.—NSA. 7901

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6.3 Non-ferrous Metals and Alloys — Heavy

6.3.3, 3.2.3

Surface Reactions of Chromium in Dilute $Cr^{51}O_4$ Solutions. NORMAN HACKERMAN AND R. A. POWERS. *J. Phys. Chem.*, **57**, No. 2, 139-142 (1953).

The quantity of chromate, dichromate, or hydrogen chromate ion sorbed on a chromium surface was measured directly by use of Cr^{51} in the anion. The effects of sorption on the metal were followed by measurements of the contact potential density against clean, smooth platinum as standard. Maximum pick-up was not in excess of a monolayer and the presence of hydroxyl, sulfate, or chloride ion in solution in sufficient concentration reduced the pick-up, indicating that competitive adsorption occurs.—MA. 7928

6.3.6, 1.6

Copper: The Science and Technology of the Metal, Its Alloys and Compounds. A. BUTTS (Editor). Book, 1954, 936 pp. (American Chemical Society Monograph Series). Reinhold Publishing Corp., New York.

Forty-six chapters by individual specialists, covering occurance, extraction and refining, powders, secondary copper, physical and chemical properties, corrosion, alloys, melting and casting, working, metallography, analysis, heat treatment, machining, jointing, cladding, applications, plating simpler compounds and biological aspects. Many of the chapters have bibliographies. Author and subject indexes.

Corrosion coverage: The subject index includes 19 references to various aspects of the corrosion of copper from acid solutions to water pipes. Chapter 18 headed "Chemical Properties and Corrosion Resistance of Copper and Copper Alloys" is by P. T. Gilbert, head of the Corrosion Section, British Non-Ferrous Metals Research Association, London. The author successively considers copper's reactions to neutral and alkaline solutions, various chemicals, sea water (with several types of attack itemized), condenser tube corrosion, fresh waters, atmosphere, soils. Also covered are stress corrosion, stress corrosion of brasses and other copper alloys, oxidation and scaling, electrode potential relationships and others. 7999

6.4 Non-ferrous Metals and Alloys — Light

6.4.2, 3.2.3,5.9.4, 2.3.9

A Study of Boehmite Formation on Aluminum Surfaces by Electron Diffraction. R. K. HART. *Trans. Faraday Soc.*, **50**, Pt. 3, No. 375, 269-273 (1954) March.

Specimens consisted of 99.995% aluminum, mechanically polished, electropolished or anodized. To obtain suitably smoothed surfaces specimens were metallographically polished and then electropolished until electron diffraction patterns revealed that the surfaces were suitable to carry out experiments. After determination of the thickness of film remaining after electropolishing, the specimen was immersed in boiling water, then

repolished and used again. A Finch-type cold-cathode diffraction camera was used, with 50-60 kV electrons and camera length 49.0 cm. The results show that boiling water acting on super-purity aluminum whether mechanically polished, electropolished or anodized, produces bubbles of a gas, presumably hydrogen, which are observed at certain points, and also a crystalline subtance detected by electron diffraction. This crystalline substance was found to be boehmite (γ-A10(OH)). It is believed that the boehmite revealed by the changing direction patterns is formed by corrosion of the aluminum and not by hydration of a pre-existing oxide film. If an initial film of "anhydrous" oxide was becoming hydrated one would expect to obtain a curve, which becomes asymptotic to a limiting value of the thickness corresponding to complete hydration. Experiment shows, however, a nearly constant rate of thickening. X-ray studies of powdered alpha or gamma alumina, boiled in distilled water under appropriate conditions have shown that neither form of alumina becomes hydrated during 20 minutes boiling. The boehmite, whether formed in the pores or on the outer surface, probably arises by combination of aluminum ions and hydroxyl ions. There are probably three reactions 1. anodic attack on the metal below the oxide $Al = Al^{+++} + 3e$; 2. cathodic hydrogen production at the oxide-liquid interface, probably $2H_2O + 2e = H_2 + 2OH^-$; 3. precipitation where the ions meet, $Al^{+++} + 3OH^- = A10(OH) + H_2O$. Considering that the size of an aluminum ion is less than half that of either an oxygen or hydroxyl ion, the inward migration of anions is less likely than the outward migration of cations. The fact that boehmite appears on the outward surface of the pre-existing amorphous film makes it fairly certain that this is the outward type of movement. The driving force is provided by the e.m.f. of the aluminum hydrogen cell. The electron diffraction method for determination of film thickness on aluminum single crystals is described.—ALL. 7721

6.4.2, 3.7.3

Soldering of Aluminium and Its Alloys with Hard Solders. (In Russian). V. A. Gorokhov. *Avtogennoe Delo* (Acetylene Welding) (USSR), **24**, No. 1, 26-28 (1953).

Tensile, metallographic, and corrosion tests were performed with aluminum and aluminum alloy parts soldered with a hard solder containing copper 28, silicon 6, and aluminum 66% (melting point 525° C), using a flux containing lithium chloride 32, sodium fluoride 10, zinc chloride 8, and potassium chloride 5% (melting point 420° C). The strength of the soldered parts was found to be satisfactory, and breaking of the specimens did not occur (with one exception) at the soldered joint. Metallographic examination showed mutual interdiffusion of the solder and the alloy, and atmospheric corrosion did not affect the strength of the soldered specimens. The method can be used for repairing of aluminum tanks, tubes, and casings.—MA. 7703

6.4.2, 3.8.4, 3.4.7

The Potential/pH Diagram for Aluminium (and Its Significance in Corrosion). C. Groot and R. M. Peekema. U. S. Atomic Energy Commission Publ., (HW-28556) August 17, 1953, 13 pp.

The available thermodynamic data for aluminum have been plotted in the form of Pourbaix's potential/pH diagram, so as to predict its corrosion properties. The thermodynamic data are reduced to three equations: 1. $Al \rightleftarrows Al^{+++} + 3e^{-1}$, 2. $2Al + 4H_2O \rightleftarrows Al_2O_3 \cdot H_2O + 6H^+ + 6e^{-1}$, 3. $Al + 3H_2O \rightleftarrows H_2AlO_3^- + 4H^+ + 3e^{-1}$ appropriate equations of potential in terms of ionic concentration are given for these reactions and are solved in pairs to give the final diagram. Thus the potential for complete cathodic protection of aluminum in acid solution is given as 1.77 V., and the boundary between the region of acidic corrosion and film protection is at pH = 4.45. The boundary between the film-protection region and that of caustic corrosion is at pH = 8.38 and intersects the film protection/cathodic protection boundary at 2.001 V. Finally, the caustic corrosion/cathodic protection boundary has a potential value of 2.44 V. at pH = 14. The diagram indicates that the useful working range of aluminum is from pH = 4.5 to pH = 8.4; aluminum is not stable with respect to its oxides in the presence of water and can not be made completely stable by cathodic protection. Aluminum is thus only usable where its oxide film is stable. Possible forms of the oxide film are briefly considered.—MA. 7731

6.4.2, 4.3.2, 3.4.4

The Dissolving Action of Hydrochloric Acid on Aluminum. (In German). T. G. O. Berg. *Z anorg. u. allgem. Chem.*, **273**, No. 1/2, 96-100 (1953) July.

The speed of the attack of hydrochloric acid on aluminum is proportional to the acid concentration c and reaches a maximum at c = 9N. It is strongly

affected by the speed with which the protecting film of aluminum hydroxide dissolves. In detail the speed of solution is affected by the following factors: 1. It is small at the beginning during a so-called "induction period" after which it rises to a constant higher value. 2. The duration of the "induction period" depends on the pretreatment of the sample surface and the concentration of the acid. 3. The attack is strongly affected by the presence of impurities, especially iron and silicon, as well as by the action of heat. 4. It rises rapidly with the concentration of the acid. 5. It reaches a maximum at c = 9N. 6. Stirring does not affect the speed of solution.—ALL. 7691

6.4.2, 6.2.5

An Example of Transposition of Phenomena and Laws of Metallography: Aluminium Alloys to Heat-Resistant Austenitic Alloys. (In French). A. PORTEVIN. *Rev. Met.*, **50**, No. 12, 809-816 (1953) December.

Discusses parallel phenomena (effect of addition elements on properties, thermal expansion behavior, corrosion cracking, etc.) occuring in precipitation-hardening aluminum alloys and austenitic ferrous alloys and useful indications arising.—BNF. 7799

6.4.2, 6.4.4

Observations on Light Alloy Continuous Castings Produced Commercially. (In German). K. E. MANN. *Aluminium*, **29**, No. 12, 497-508 (1953) December.

Investigation of segregation, cracking, surface defects, micro-structure, strength, etc. of continuously cast aluminum and magnesium alloys.—BNF. 7822

6.4.4

A Contribution to Magnesium Refining. KARL ERNST MANN. *Z. Metallkunde*, **44**, No. 6, 264-266 (1953).

Magnesium melts can be freed from iron, silicon, and aluminum to a considerable extent, and in a lesser degree from manganese, by the addition of zirconium. The added zirconium can then be removed by a current of hydrogen or, less effective, chlorine, without loss of purity in other respects. The removal of zirconium can be controlled by means of fracture specimens without the need for analysis. Magnesium refined in this way has excellent corrosion-resistance. —MA. 7814

6.4.2, 5.9.4

Electron Currents in Thin Oxide Films on Aluminium. A. CHARLESBY. *Proc. Phys. Soc.* (London), (B) **66**, No. 7, 533-541 (1953).

At field strengths lower than those required for anodiznig aluminum [*cf. ibid.*, No. 4, 317-319 (1953) April] small currents are still observed which do not, however, lead to the growth of the anodic film. This electron current should theoretically be i = A sinh BF, where F is the field across the film, and A and B depend on the temperature and barrier height. A and B have been measured. When this expression is added to the ionic current formula, a comprehensive current-voltage formula is obtained in good agreement with experiment.—MA. 7431

6.4.2, 5.9.2

Aluminium Polishing. *Light Metal Age*, **11**, No. 3/4, 31 (1953) April.

"Alchemize" is a non-electrolytic process by which all alloys of aluminum, except silicon castings, may be cleaned and brightened to a mirror finish. Equipment involved is an "Alchemize" solution tank, heated to 180°F.-230°F. and two rinse tanks. The aluminum must be cleaned of greases, oils or soils before "Alchemizing." Parts are racked or basket dipped, and immediately following the dip are rinsed in cold water, transferred to a second rinse containing 20 to 40 percent nitric acid and water solution, and re-rinsed in water.—ALL. 7170

6.4.2, 5.9.2

How to Prepare Aluminum for Painting. A. T. THIBADEAU. *Ind. Finishing*, **29**, 60, 62, 67-68 (1953) July.

Cleaning processes and equipment. Photographs.—MR. 7236

6.4.4, 3.7.2, 3.5.8

Further Progress in the Development of Magnesium-Zirconium Alloys to Give Good Creep and Fatigue Properties Between 500° and 650°F. (260° and 370°C). C. J. P BALL, A. C. JESSUP, P. A. FISHER, D. J. WHITEHEAD, AND J. B. WILSON. *J. Metals* (Trans. AIME), **5**, No. 7, 924-931 (1953).

A study has been made of the creep and fatigue properties of magnesium-thorium (1.9-4.7%)-zirconium (0.7%), magnesium-thorium (3%)-cerium-Mischmetall (1.4-4.0%)-zirconium (0.7%), and magnesium-thorium (1.9-3.85%)-zinc (0.7-4.7%)-zirconium (0.44-0.81%) alloys, in the green sand-cast condition, with and without-solution treatment. The results show that the magnesium-thorium-zinc-zirconium alloys, when free from cerium-Mischmetall, have a high level of creep resistance at temperatures of 600°F. (315°C.) and above. The optimum properties are obtained at a ratio of thorium: zinc = 1.3; this corresponds to a nominal composition of thorium 3 and zinc 2.5%, and such a material with the composition (for specification purposes) of thorium 2.5-3.5, zinc 1.75-2.5, and zirconium 0.7% is designated Elektron Magnesium alloy ZT1. It possesses superior creep-resistance to the equivalent zinc-free alloy, has good fatigue properties at room and elevated temperatures, combined with good tensile properties—which are well retained over the range 527°-662°F. (292°-350°C.)—and good corrosion-resistance. The alloy is easily sand-cast, is free from micro-porosity, and shows little tendency to hot-cracking. 15 references.—MA. 7415

6.4.4, 7.1

Magnesium to the Fore. *Chem. Eng. News*, **31**, 4778, 4781 (1953) Nov. 16.

Briefly describes chemical surface treatments of magnesium for resisting corrosion and abrasion. Also discusses experiments using magnesium powder as fuel in internal combustion engines.—BTR. 7309

6.4.5, 3.2.3, 3.8.4

Kinetics of the Reaction Between Lithium and Water Vapor. BRUCE E. DEAL AND H. J. SVEC. Ames Lab. (ISC-390), July, 1953, 32 pp.; *J. Am. Chem. Soc.*, **75**, 6173-6175 (1953) Dec. 20.

A critical examination of the reaction between lithium and water vapor has been made at 35.0, 45.0, 55.0, 65.0, and 75.0°C. Analyses of the products indicated that lithium hydroxide and hydrogen are the species formed, corresponding to the equation $2Li + 2H_2O \rightarrow 2LiOH + H_2$. Three rate variables have been examined for this reaction: time, pressure, and temperature. The reaction data have been found to obey the logarithmic rate law w = k log (1 + 0.45t), where w = weight of water reacted per unit area of lithium surface, t = time, and k is the rate constant. Reaction rate decreases as a function of pressure at any particular temperature, becoming independent of the water-vapor pressure when the pressure is reduced below a certain limit. The Arrhenius equation li k = —E/RT + c, where k = reaction rate constant, E = activation energy, T = absolute temperature, and R and c are constants, was used to determine the activation energy. Values for the activation energy of the lithium-water vapor reaction were estimated to be 6.2 kcal/mole when the water vapor pressure was about 50 mm. Hg and 5.5 kcal/mole when the water vapor pressure was approximately 100 mm. Hg.—NSA. 7435

6.6 Non-Metallic Materials

6.6.4

Delanium Carbon and Graphite. A. W. MORRISON. *Research* (London), **6**, No. 1, 29-35 (1953) Jan.

Properties, uses and manufacture of Delanium carbon and graphite. A raw material with chemical and physical properties intermediate between coke and pitch, such as coking coal, is used in the manufacture of Delanium carbon to cement particles of coke. The corrosion resistant qualities of the graphite coupled with its high thermal conductivity which is higher than that of most metals, for example mild and stainless steels, make it an ideal material for a wide variety of industrial problems. Illustrations, 13 references.—INCO. 6141

6.6.4, 8.8.1

Carbon and Graphite for Chemical Plant. A. W. MORRISON, B. W. FREEMAN, AND P. G. R. HAINES. *Chem. & Process Eng.*, **34**, 315-320 (1953) October.

Describes manufacture and properties of carbon and graphite and equipment made of these materials such as heat exchangers, packed towers, pumps, and ejectors. Shows how corrosion resistance makes possible wide range of special duties in chemical industries. Photographs, tables, graphs, diagrams. 8 references.—BTR. 7841

6.6.6

Determination of Progressive Corrosion of Glass Tank Refractories. P. G. HEROLD AND V. P. MAHESHWARY. Bull. University of Missouri, School of Mines & Metallurgy (Technical Series), No. 82, 1-28 (1952) Dec.

A comprehensive review of literature dealing with slag attack on refractories is given. The viscosity of the corrosive liquid in contact with refractory was used as a measure of the progressive solution of the refractory. Additional tests included Pyrometric Cone Equivalent test, hot load test, and the slag cavity test.—BNF. 7734

6.7 Duplex Materials

6.7.2

Metal-Ceramic Wall Lengthens Thermocouple Life. J. B. MCSHERRY. *Iron Age*, **172**, No. 18, 100-101 (1953) October 29.

The metal-ceramic LT1 (Hayes Stellite Co.) is 77% chromium and 23% aluminum oxide. The metal imparts good thermal conductivity and shock resistance; the aluminum oxide has a

high melting point, and gives resistance to deformation, oxidation and solution attack by molten metals. The thermal conductivity is about that of cast iron. ⅛ in. wall round the thermocouple well is ample protection.—BNF. 7842

6.7.2
Cemented Carbide Families Grow. J. S. GILLESPIE AND I. L. WALLACE. *Steel*, **130**, 84 (1952) April 21.

Discusses the above. Includes new developments, properties, corrosion and heat-resistance data and applications.—BTR. 6697

7. EQUIPMENT

7.1 Engines, Bearings and Turbines

7.1, 3.7.4
Investigation of Effects of Grain Size Upon Engine Life of Cast AMS 5385 Gas Turbine Blades. C. A. HOFFMAN AND C. A. GYORGAK. Lewis Flight Propulsion Lab. Nat'l. Advisory Comm. Aeronaut., RM E53D06, July 6, 1953, 21 pp.

Investigation to determine the effects of pouring temperature and grain size on uniformity of lives and initial failure times of groups of experimentally cast AMS 5385 (containing 2.5 and 1.75-3.75% nickel) gas turbine blades aged 24 hours at 1350°F., and to relate individual lives of these blades to grain sizes. Grain sizes varied from 4-11, 200 (ASTM 8) grains per cross section. Commercially produced AMS 5385 blades were used as a control group. The blades were operated in a small gas turbine at 1450°F. and a midspan stress of 19,000 lbs. per square inch. A correlation was found between number of grains per blade cross section and blade life for the experimentally cast blades; longer life was associated with the coarser grain sizes. Initial failure time and uniformity of life was better for the experimentally cast blades poured at the higher nominal temperature than those poured at the lower nominal temperature. Experimentally cast coarse-grained blades had better uniformity, similar initial failure time, but lower mean life than a group of commercially cast coarse-grain blades. Appendix, illustrations, 8 references.—INCO. 7739

7.1, 5.3.2
Experimental Plating of Internal Engine Parts. GEORGE W. GRUPP. *Metal Finishing*, 51, No. 7, 53-55 (1953).

A study was made of the effectiveness as a protective coating for internal engine parts, of various combinations of electrodeposited nickel/zinc and cadmium/tin. The metals were applied consecutively and alloyed by heat-treatment at 700°F. (370°C.) in the case of nickel/zinc and 330°F. (165°C.) in the case of cadmium/tin. The degree of protection was assessed by operating treated aircraft engines for 8 hr. and subsequent exposure to sea-air for 10 days. The cadmium/tin coatings were shown to give excellent protection against corrosion. The plated surfaces were shown to be in very good condition after 500 operating hr. Schedules for hand and automatic plating are given.—MA. 7707

7.1, 6.3.8
The Development of a Copper-Silver-Lead Alloy for Bearings. G. LLEWELYN. *Metallurgia*, **48**, No. 289, 215-220 (1953).

A bearing alloy containing copper 30,

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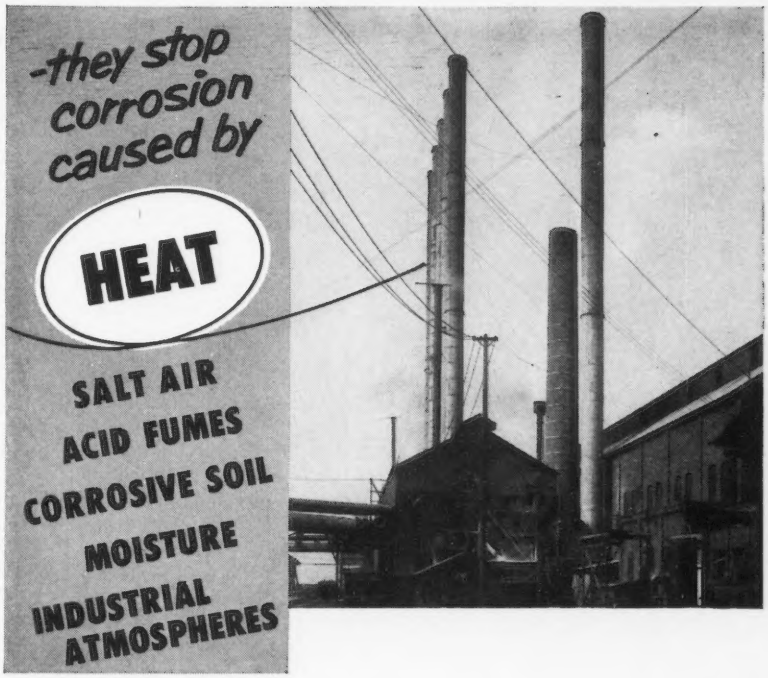

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silver 30, and lead 40% has been developed on a laboratory scale. It can be readily bonded to mild steel, using normal casting techniques, and fulfills the major requirements of a bearing alloy. In some instances the properties are equal to, and in others better than, those of the usual alloys. The mechanical properties at elevated temperatures are better than those of the tin-base alloy, while the compressive strength at temperatures is equal to that of the copper-30% lead alloy and much better than the tin-base alloy. Thus, the alloy should be quite suitable for use with high loads at bearing temperatures and should not suffer from fatigue failure. The coefficient of friction is low owing to the formation of a thin surface film of lead during running. The corrosion-resistance, although not so high as that of the tin-base alloy, is good enough to ensure no serious trouble, and the alloy can accommodate foreign matter in sufficient amount to ensure trouble-free running. —MA. 7751

7.1, 8.9.5, 2.2.4

Operation of a Marine Gas Turbine Under Sea Conditions. J. LAMB AND R. M. DUGGAN. *Trans. Inst. Marine Engrs.*, **65,** No. 12, 277-304 (1953) Dec.; condensed version: *Shipbuilding and Shipping Record,* **82,** No. 21, 676-679 (1953) Nov. 19.

Details of the results obtained over two years with the first gas turbine to be used for the propulsion of a merchant ship (the *Auris*). The machinery layout is described and the general performance of the turbine set under varying sea and atmospheric conditions is outlined. Each component is discussed separately, including the effect of salt in the air on the compressors and of fuel ash on turbine blading. Particulars are given of mechanical defects encountered and information is given regarding the heat resisting properties of special steels employed and of the composition of deposits found in the high-pressure turbine and heat exchanger.—BNF. 7747

7.2 Valves, Pipes and Meters

7.2, 8.4.3, 3.5.8

Vulnerability of Drill Pipe to Corrosion Fatigue. STANLEY C. MOORE AND A. P. FARR. *World Oil,* **137,** 200, 202, 204, 206, 208 (1953) October.

Discusses corrosion problems in drilling oil wells in the Permian Basin. Graph, photographs. 8 references.—BTR. 7850

7.2, 8.8.1

Small Corrosion-Resistant Valves for Remote Chemical Service. G. J. SELVIN. Brookhaven National Lab., May 1, 1952, 8pp.; *Nucleonics,* **10,** No. 12, 72-73 (1952) Dec.

In the chemical processing of highly radioactive materials, valves are needed that are resistant to corrosion by all strong acids and alkalies up to 105°C. The squeeze valve, developed for use on Tygon tubing, is of stainless steel. The diaphragm valve, for use with rigid tubing, is of Type 304 stainless with hardware and fittings of Types 303 and 304 stainless steel, respectively.—INCO. 5884

7.3 Pumps, Compressors, Propellers and Impellers

7.3, 5.3.2

Nickel Plating of Aluminium Propeller Blades. *Plating,* **40,** No. 7, 774-775 (1953).

A short account of the development of a rubber-bonded plated-nickel coating on solid Duralumin propeller blades is given. Use of conventional methods for plating on aluminum did not produce the quality of plating required for the severe service conditions, and the coating failed owing to rapid galvanic corrosion caused by the nickel/aluminum couple. Illustrations, but no technical details of the process, are included.—MA. 7802

7.4 Heat Exchangers

7.4.2

Calculation and Installation of Copper Tube Radiation Heating. (In French and German). A. KOLLMAR. *Pro-Metal,* **6,** No. 33, 167-182 (1953).

Data for the calculation of the loss of pressure in a copper-tube circuit are given and a number of examples are worked out. The full calculation necessary for a projected installation is reviewed; the following steps are necessary: 1. calculation of heat losses; 2. calculation of radiating area; 3. inclusion of the ceiling radiation panel area in the plan of the building; and 4. calculation of the distributing circuit. It may be more economical to use copper tubes for the heating circuit and iron pipes for distribution; there is some risk of galvanic corrosion at points of contact, but insulating inserts or replaceable joint fittings can overcome this problem.—MA. 7767

7.4.2, 5.11

Air-Preheater Design as Affected by Fuel Characteristics. HILMER KARLSSON AND W. E. HAMMOND. *Trans. Am. Soc. Mech. Engrs.,* **75,** 711-718; disc., 718-722 (1953) July.

Discusses equipment design to prevent corrosion and plugging. Graphs, diagrams.—BTR.

7.4.2, 7.6.4, 4.2.3

Work in Great Britain on Corrosion and Deposits in Air Preheaters. A. A. BERK. U. S. Dept. Interior. *Mech. Eng.,* **75,** No. 7, 545-546 (1953) July.

Report on information obtained in England from the Boiler Availability Committee. Lab findings include mechanism for sulfur trioxide formation, methods for its removal from the flue gases, methods for its determination and for predicting whether the sulfur trioxide content is dangerously high. Good correlation is obtained between special dew-point measurements and corrosion probe findings. Most serious acid build up occurs 40-80° F. below the dew-point, and the corrosion probe corroborates this temperature range to be the most troublesome for corrosion and deposits. Immunity period in new boilers, and the cleaning of air preheaters and superheaters are discussed.—INCO. 7650

7.4.2, 1.6

Bridgeport Condenser and Heat Exchanger Tube Handbook. 1953, 156 pages. Bridgeport Brass Co., Bridgeport, Conn.

This comprehensive book covers the Bridgeport Brass Company's condenser tubes from the development of condenser tube alloys, through installation. Corrosion from water, impingement, dezincification, effect of temperature on corrosion, galvanic corrosion, effects of vibration on corrosion and the uses of duplex tubing in corrosive environments are covered in detail. Many tables and graphs of data are given permitting comparison of the characteristics of several common types of tubes. Numerous discussions of tubing installations in industry, including petrochemical, petroleum refining, chemical processing, sugar refining, refrigeration and steam power plants, are given. 6064

7.5.2, 4.3.2

Materials Handling. T. W. RODES. *Ind. and Eng. Chem.,* **44,** No. 11, 137A-138A, 140A (1952) Nov.

A venting drum plug of cast iron embodying a disk of carbon is used to adequately and effectively permit the escape of sulfuric acid fumes without danger of acid spillage. Diagrams and tables.—INCO. 5880

7.6 Unit Process Equipment

7.6.4

Bimetallic Water Heaters Brazed for Strong, Tight Joints. A. H. TRAGESER. *Iron Age,* **172,** No. 19, 176-177 (1953) Nov. 5.

Water heaters, of steel sheet lined with thin copper sheet for corrosion protection, are manufactured by silver brazing or soldering the seams.—BNF. 7302

7.6.4

Causes and Prevention of Corrosion of Soldered Seams in Water Heaters. (In German). W. SAVELSBERG. *Metalloberflache,* A, **7,** No. 11, A173-A174 (1953) Nov.

A brief elementary electrochemical discussion of corrosion of soldered joints, due to contact of different metals, with reference also to other factors such as stray currents. It is pointed out that contact corrosion can only be avoided by complete tinning or lacquering of the inside of the heater.—BNF. 7232

7.6.4

Pressurizing HPHW Systems with Nitrogen and Other Methods. J. R. KELL. Partner, Oscar Faber & Partners.

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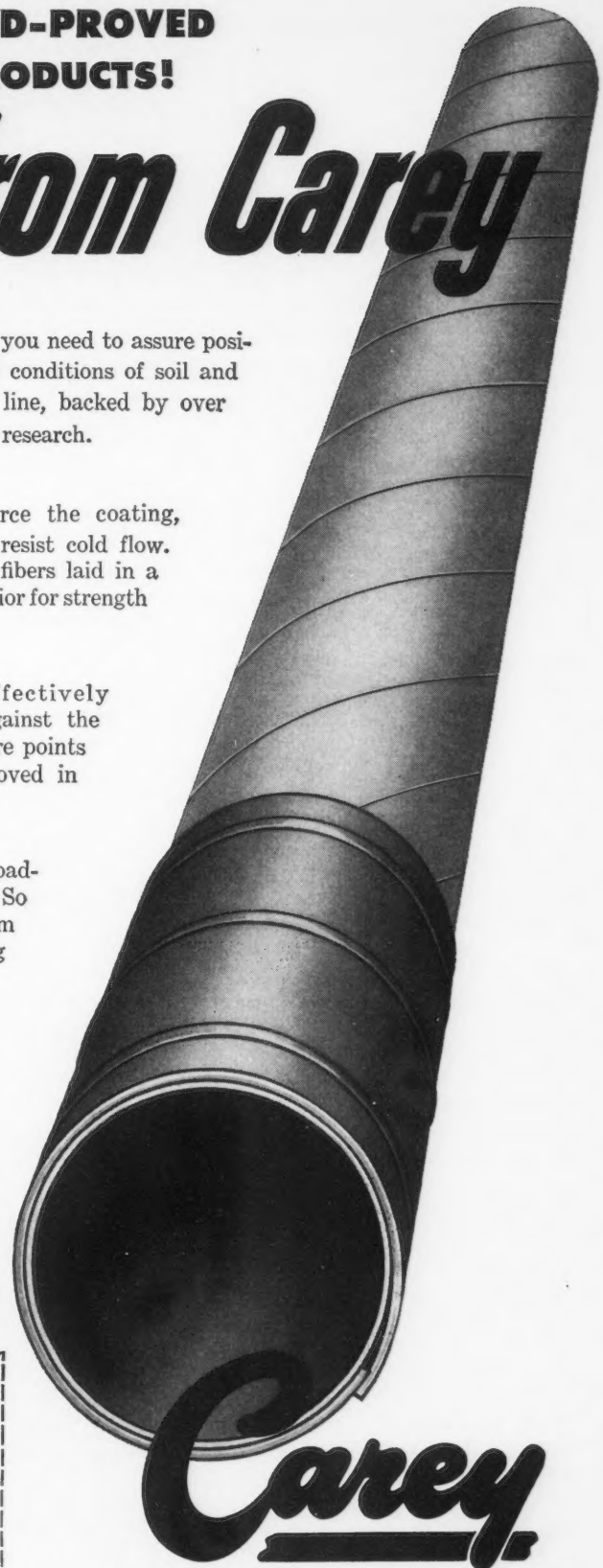

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Heating, Piping, Air Conditioning, **25,** No. 2, 84-87 (1953) February.

A high pressure hot water system (HPHW) usually signifies one working at pressures from about 80 to 250 psig or over. Methods of pressurizing are by an elevated tank, an artificial head, steam, or a gas, such as air or nitrogen. Variations of pressurizing by air or nitrogen, use of nitrogen instead of air, effect of pressure on solubility, and corrosive effect of oxygen are discussed. Pressurization with nitrogen instead of air minimizes internal corrosion. Diagrams, tables and photograph.—INCO. 6952

7.6.4, 1.3, 3.5.8

Caustic Cracking in Marine Scotch Boilers. W. McCLIMONT. (Abridged Form of Report No. 79 of Brit. Shipbuilding Res. Assoc.) *Engineering*, **175,** 219-220 (1953) Feb. 13.

Commentary review of published literature. Discusses intercrystalline fractures which occur in boiler components under influence of static stress concentrations and in contact with fairly concentrated solutions of sodium hydroxide. 28 references.—BTR. 7122

7.6.4, 4.6.2, 5.7.7

Water Treatment for Low-Pressure Heating Boilers. LEO I. PINCUS. Water Service Laboratories, Inc., New York. *Power*, **97,** No. 8, 118-119 (1953) Aug.

Corrosion and scale formation in low-pressure boilers can be held to a minimum by maintaining the boiler water at a hydroxide alkalinity of 100-350 ppm. and total alkalinity at 300-500 ppm., both expressed as calcium carbonate. This is done by initially dosing the boiler water with such chemicals as sodium ortho- or metasilicate, sodium carbonate, trisodium phosphate, or alkaline sodium chromate and, depending on condensate losses and amount of blowdown, periodically adding sufficient treatment chemical to the feed water to maintain these alkalinity levels. Alkalinities up to 1000 ppm. do no harm.

Intelligent operation for minimizing corrosion and scale damage requires a knowledge of boiler capacity, analysis of untreated boiler water and raw feed water, and constant check-up for presence of leaks and other sources of loss. —PDA. 7798

7.6.6, 8.4.3

Corrosion in Sulfate Digesters of Norwegian Mills. (In English). B. ROALD. *Norsk Skogind.*, **7,** No. 11, 382-388 (1953); *Paper Ind.*, **36,** No. 4, 412 (1954) July.

Survey comprises the visual inspection of scale and corrosion patterns and Audigage wall thickness measurements. Corrosion rates are less than 0.9 mm. per annum. In those mills which had recently installed spray-type recovery furnaces, the corrosion rate increased considerably (due possibly to increased sulfidities of the white liquors). Data obtained in Norway are the same as those in other countries. Corrosion rates were compared in terms of millimeters per 1000 cooks, rather than in millimeters corrosion per annum. Differences are shown in bar graph. Possible causes of corrosion are discussed from the standpoint of steel composition and structure, liquor composition and digester operating practice. Photomicrograph taken of the edge of a test plate after a year's exposure in a digester shows the preferential attack on the ferrite. In discussing the as yet incompletely understood causes of corrosion, the author recommends regular digester inspection, with the object of correcting localized attack before serious damage results and keeping mill management fully informed of the extent of such corrosion. Up to the present, Norwegian mills have not encountered the excessive attacks reported by some foreign mills.—INCO. 7855

7.6.6, 8.5.3

Corrosion in Kraft Digesters. L. RUUS AND L. STOCKMAN. *Svensk Papperstidn.*, **56,** No. 22, 857-865 (1953); *Paper Ind.*, **35,** No. 11, 1242 (1954) Feb.

Interim report concerned with the corrosive action of various components of the white liquor and with the effect of composition of steels used in digester construction in 7 mills. Composition of the white liquor has a definite effect on corrosion, which increases with increasing amounts of sodium monosulfide, sodium hydroxide, $Na_2S_2O_3$, and Na_2S_n. It is possible to decrease or to stop corrosion by means of inhibitors; but, to date, those which were studied were found to be too expensive. With high carbon and silicon content of the steel, corrosion seems to increase. Various welding materials investigated show differences in resistance to corrosion; those with a low silicon content seem to be the more resistant.—INCO. 7809

7.7 Electrical-Telephone and Radio

7.7

How to Select Connectors for Aluminium Conductors. HENRY DUPRE. *Materials and Methods*, **38,** No. 2, 96-99 (1953).

The problems created by the use of aluminum to replace copper for electrical purposes are reviewed. A consideration of the three factors involved in designing the contact area of a connector is given, and the additional problems of correct strength and conductivity of the connector are outlined. Galvanic corrosion of aluminum in contact with dissimilar metals is discussed, and the prevention of oxidation at joints is mentioned. The industrial applications, adaptability, and properties of aluminum joints and connectors are also referred to.—MA. 7730

7.7, 3.2.3, 2.3.5

The Influence of the Oxidizing Effect of Atmospheric Air on the Performance of Electrical Contacts. (In German). R. PALME. Schweiz. Arch. angew. Wiss. u. Tecknik, **19,** No. 6, 177-184 (1953) June.

The behavior of contacts made of tungsten, copper, silver, 60:40 silver-nickel, 94:6 silver-cadmium oxide, and 92.5:7.5 silver-copper was studied in experiments using 440-V. 50-amp., A.C., one switch operation/min., 50,000 in each test. The contact resistance and the weight of the contacts were determined before and after the test. The oxidation of small sheet specimens was studied at 500° and 700°C, and a special test was devised to examine the adhesion of the oxide to the surface. Contact resistance and weight loss were also determined in tests using 220-V., 20-amp., D.C., with one switching operation every second, a force of 1 kg. on the contacts, and a total of 20,000 switching operations. Results are given for the various tests and a number of examples of practical applications for various contact materials are quoted.—MA. 7863

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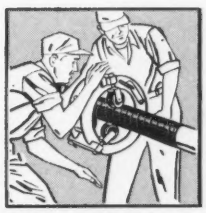

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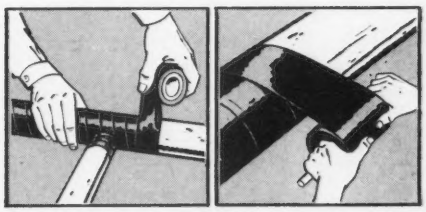

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